

FLAT PANEL DISPLAY SUBSTRATE TESTING SYSTEM

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BACKGROUND OF THE INVENTION

Field of the Invention

5 This invention relates generally to the field of systems for processing of large substrates, and more particularly to high-throughput electron-beam flat panel display substrate (FPDS) testing systems.

Description of the Related Art

10 The use of electron beams to inspect and electrically test flat panel display (FPD) substrates (FPDSs) is an established technique. For FPDS testing, it is necessary to be able to test 100% of the pixels on the FPDS surface since, typically, a display with more than a few defective pixels is unusable. In some cases, if defective pixels are detected early enough in the manufacturing process, these pixels can be repaired. In other cases, if a substrate is found to have numerous
15 defective pixels, it is more economical to scrap that FPDS prior to further processing. FPDS testing also provides process feedback: if successive FPDSs show increasing numbers of defective pixels, a deviation from proper process parameters (etch, deposition, lithography, etc.) may have occurred, which must be corrected quickly to restore normal production yields. 100% pixel inspection requires that every pixel on
20 the FPDS must be able to be targeted by at least one of the electron beams from the linear column array.

 Prior art e-beam systems for testing FPDSs employ a process chamber, pumped down to high vacuum, for containing one or more electron beam columns. The electron beams generated by these columns are scanned across the surface of
25 the FPDS under test, thereby causing the emission of secondary electrons (SEs) and backscattered electrons (BSEs) which are collected by a detector, as is familiar to those skilled in the art. A typical FPD has a large number of pixels, arranged in an

X-Y array, each consisting of a thin-film transistor connected to a large pixel electrode. For proper operation of the FPD, it is necessary for nearly all pixels to be functional. During FPD fabrication, large numbers of pixels are connected together to "shorting bars", which, in turn, are connected to test pads around the periphery of each FPD on the FPDS. For electrical testing of the FPDS, connections are made to each of these test pads and voltages are thereby applied to the pixels in all of the FPDs on the FPDS. These electrical connections are typically made using a "probe frame", which contains a large number of contactors physically arranged to match the placement of test pads on the FPDS. After insertion of an FPDS into the process chamber, the probe frame (or its functional equivalent) is lowered onto the FPDS. Then, using the electron beams from the columns in the process chamber, electrical measurements of pixel performance may be made in order to detect if any pixels are defective.

Prior art testing systems typically employ a loadlock, attached to the process chamber, into which FPDSs for testing are loaded, pumped down, then inserted into the process chamber. After the probe frame has been lowered onto the FPDS, it may be aligned with the FPDS. If alignment is performed, no e-beam testing can be performed during the alignment process, representing a loss in system throughput. FPDSs are typically >2 m in X-Y, but <1 mm thick, and are made of glass – transporting such a delicate object clearly represents a significant difficulty, both in terms of throughput (i.e., the maximum transport speed and acceleration may be limited), and in terms of potential breakage within the system (leading to system downtime). After e-beam testing of the FPDS is completed, the probe frame is lifted off the FPDS, and the FPDS is then removed from the process chamber, followed by insertion of another FPDS into the process chamber, etc.

FIG. 1 is a schematic of a prior art multiple electron beam FPDS testing system. A typical FPDS contains a number of flat panel displays (FPDs) – six FPDs are shown in the FPDS 1398 of FIG. 1. Each FPD contains a large number of pixels arranged in an X-Y configuration. At the stage of FPD manufacturing where e-beam testing is normally performed, each pixel typically comprises a thin-film transistor (TFT) connected to a pixel electrode (generally larger than 100 μm in both dimensions). To facilitate testing, a large number of the TFT sources are shorted together with shorting bars, connected to test pads (TPs) around the periphery of

each FPD on the FPDS. Similarly, large numbers of the TFT gates are also shorted together to other shorting bars, connected to another set of TPs. The prior art e-beam testing process is discussed in U.S. Patent Application Ser. No. 11/225,376 filed September 12, 2005 incorporated by reference herein. In prior art e-beam
5 FPDS testing systems as shown in FIG. 1, after the FPDS **1398** to be tested has been inserted into the process chamber (not shown), probe frame **1399** is lowered onto FPDS **1398**. Probe frame **1399** contains a large number of contactors (not shown) which must align with, and make good electrical contact to, every one of the TPs on the FPDS. If any contactors fail to make contact with the TPs, it will not be
10 possible to fully test the FPDS, with the result that substantial numbers of defective pixels may go undetected. Since the TPs are generally positioned around the border of each FPD, and the FPDS contains a number of FPDs, probe frame **1399** must be designed with connections both to the perimeter and the middle of the FPDS – the cross-members in probe frame **1399** crossing FPDS **1398** contain these
15 connections.

In FIG. 1, four electron beam columns **1311** generate electron beams **1330**, each being scanned over an area of the FPDS **1398** typically >300 mm square. The impact of the electron beams **1330** with FPDS **1398** causes the emission of secondary electrons (SEs) and backscattered electrons (BSEs). Signal electrons
20 **1395** may comprise only SEs, only BSEs, or a mixture of SEs and BSEs. The electron optics is configured to ensure that the signal electrons **1395** from each beam **1330** are collected only by the detector **1390** associated with that particular beam **1330** in order to avoid cross-talk between pixel test signals.

Because the square scan areas of the beams **1330** do not fully span the width
25 of FPDS **1398**, it is necessary to mount FPDS **1398** on an X-Y stage in order to position any point on the FPDS **1398** surface under one of the beams **1330**. The stage comprises motion axis position sensors **1386** and **1387** and stage motors **1360** and **1361**, as is familiar to those skilled in the art. Because the dimensions of the FPDS are >2 m in each axis, the X-Y stage must be very large, leading to high cost
30 and potential reliability and maintenance issues. It would be advantageous to eliminate the need for an X-Y stage in an FPDS testing system.

Cables **1312** connect columns **1311** to optics control **1301**. Cables **1391** connect detectors **1390** to detectors control **1304**. Data lines **1310** connect position

sensors **1386** and **1387** to X-Y position readout **1302**. Cables **1325** connect stage motors **1360** and **1361** to stage control **1300**. Controls **1300-1302**, and **1304**, are connected to system control **1303** by control links **1326**, **1320**, **1319**, and **1392**, respectively. Cable **1385** conducts control signals to the probe frame **1399** from system control **1303**.

There are a number of disadvantages for prior art FPDS electron-beam testing methods:

- 1) The FPDS, with typical dimensions >2 m in X and Y, must be supported during testing by a large and expensive X-Y stage, which enables the FPDS to be moved around under one or more electron beams for testing of the entire FPDS surface (100% of all pixels).
- 2) Connection to the test pads on the FPDS requires a probe frame, which remains in the process chamber and must be aligned to the test pads for proper electrical connections. The use of a probe frame has several significant disadvantages:
 - a. The probe frame-to-FPDS alignment step is performed within the process chamber – it is not possible to test the FPDS during this step, thus system throughput is adversely affected. In addition, it may be more difficult to achieve good alignment due to the difficulty of working within the confines of the process chamber.
 - b. If the probe frame-to-FPDS alignment is accelerated or omitted to improve throughput, there will be cases in which some test pads are not connected to the testing system electronics, causing large numbers of pixels to go untested.
 - c. When there is a change in the FPDS design, the process chamber must be opened to replace the probe frame since the probe frame design must be consistent with the particular arrangement of test pads on the FPDS. This has a serious negative impact on throughput and tool availability.
 - d. If there is a failure of the probe frame, the process chamber must be opened for replacement or repair of the probe frame – during this time, the system is down.

e. Because prior art systems use an X-Y stage to move the FPDS during testing, moving cables are required to make contact to the probe frame which is moving along with the FPDS. It is well known by those skilled in the art that two major sources of system unreliability are cables and cable connectors, especially if the cables connect to a moving assembly such as the probe frame.

- 3) Prior art electron-beam FPDS testing systems generally transport the FPDS without any protective surroundings, e.g. a pallet, for physical support – this raises issues of potential FPDS breakage within the FPDS testing system, leading to system downtime while fragments of the broken FPDS are removed from valves, mechanisms, pump openings, etc.
- 4) In prior art testing systems, when the FPD fab switches from one size FPDS to another (usually larger) size FPDS, typically either substantial changes to the testing system are required, or an entirely new testing system is needed.

Thus there is a need for an electron-beam FPDS testing system with the following improvements from prior art e-beam FPDS testing systems:

- 1) Elimination of the need for a large and expensive X-Y stage for supporting the FPDS under test.
- 2) Elimination of a probe frame which remains in the process chamber, and substituting a method of connecting to the test pads on the FPDS which eliminates the disadvantages of prior art system designs described above.
- 3) Elimination of all moving cables and cable connectors between the FPDS under test and the system.
- 4) Adding a capability for rapid changeover from one size FPDS to another size FPDS with minimal or no system downtime.

SUMMARY OF THE INVENTION

The present invention includes an equally spaced linear array of electron beam columns, each configured with a main scan axis parallel to the linear array of

electron beam columns such that the scans of neighboring columns overlap, thereby providing 100% scanning across the full width of the FPDS under test. The multiple electron beam columns may instead be multiple ion beam columns, each generating a single ion beam which is focused onto the surface of the FPDS for imaging and/or testing purposes. The present invention provides a system for testing of FPDSs which addresses all three areas for improvement described in the background of the invention:

1) Instead of the X-Y stage, the present invention employs a set of bi-directional motor-driven rollers to move a pallet containing the FPDS along one axis within the process chamber, while a line of e-beam columns (oriented perpendicularly to the FPDS motion axis) tests pixels across the full width of the FPDS. The pallet provides physical support and protection for the delicate FPDS at all times within the system.

2) Instead of using a probe frame, the present invention uses the pallet described above to also provide electrical connection to the test pads on the FPDS. Advantages of electrically connecting to the FPDS using a pallet include:

- a. Since the pallet travels with the FPDS throughout the system, it does not remain within the process chamber. Alignment of contactors to test pads may be done simultaneously with e-beam testing of another FPDS (thereby improving throughput).
- b. Since alignment of the contactors to the test pads is done outside the confines of the process chamber, potentially alignment may be easier and/or faster. Also, since alignment now has no effect on throughput, it is possible take sufficient time for alignment to ensure that all contactors are making proper contact prior to insertion of the pallet into the process chamber – thus e-beam testing need never be aborted due to contact failure within the process chamber.
- c. When there is a change in the FPDS design, different pallets (adapted to the new FPDS design) can be immediately

substituted with no need to open the process chamber and with no loss in throughput or system availability.

- d. If there is a failure of the contactors on a particular pallet, another pallet may be substituted, with no need for opening the process chamber and with minimal throughput effect.

3) Rather than using moving cables and cable connectors between the FPDS under test and the system, a method of wireless communication is used to/from the pallet as it moves within the process chamber, thereby improving system reliability.

4) Since the pallet transport mechanisms deal only with pallets and not with the FPDS, it is simple to convert the testing system from one size FPDS to another size by using a different pallet (having the same X-Y outer dimensions), with no system downtime for the conversion.

The detailed specification is divided into a number of sections, each describing various aspects of the present invention. Some of these sections apply to both embodiments, while others apply to only the first embodiment or only to the second embodiment. Each section is described briefly below:

Flat Panel Display Substrate Pallet Design

FIGS. 3-9 describe the overall mechanical design of the FPDS pallet used in both embodiments. The pallet has a pallet top and a pallet bottom, with provision for the FPDS to be clamped between them.

Internal Structure and Electronics of the Pallet

FIGS. 10-17 describe the electronics within the pallet used in both embodiments, including the internal drive electronics which provides voltages to contactors which connect to test pads on the FPDS under test, as well as wireless data links to/from the system control, and three alternative means for supplying power to charge batteries in the pallet.

Pin Plate and Robot End Effector Design

FIGS. 18-25 describe the design of the pin plate used to disassemble pallets, and the robot end effector used to remove FPDSs from disassembled pallets. The pin plate and end effector designs apply to both the first and second embodiments.

5 Detailed Pallet Disassembly Procedure

FIGS. 26-33 show the disassembly procedure for pallets in detail. Two sets of pins (long and short) on the pin plate are able to separate the pallet top, FPDS, and pallet bottom in one vertical actuator-driven motion. After the pallet is separated, the robot end effector is able to enter the assembly (which is being held apart by the pin
10 plate), remove the already-tested FPDS, insert another FPDS (ready for testing), and then reassemble the pallet. This procedure applies to both the first and second embodiments.

Procedure for Aligning the Pallet Top to the FPDS

FIGS. 34-40 illustrate a procedure for aligning the pallet top with the FPDS.
15 This alignment is necessary to ensure that all of the large number of contactors in the pallet top align (to within a few μm) with the test pads on the FPDS under test. Two alternative means for detecting alignment marks on the FPDS are described, along with a procedure for precisely moving the pallet top in X-Y-Yaw relative to the FPDS. After proper alignment has been achieved, the pallet top and pallet bottom
20 are firmly locked together, clamping the FPDS under test between them. This alignment and clamping procedure applies to both the first and second embodiments.

First Embodiment of an FPDS Testing System

FIGS. 41-44 describe a first embodiment of the present invention, comprising
25 three subsystems: a pallet elevator, a dual loadlock, and a process chamber. The pallet elevator is the interface to the FPD fab, while the dual loadlock enables the process chamber to run nonstop testing of FPDSs using a multiple electron beam column assembly with no down-time for pumping down or venting the loadlock.

Pallet X-Y-Yaw Positional Measurement System

FIGS. 45-50 discuss a system for measuring the X-Y-Yaw position of the pallet during e-beam testing. Given the X-Y-Yaw positional data, the system control directs the optics control to deflect the multiple e-beams to correct for any positional errors. The X-Y-Yaw positional measurement system applies to both the first and second embodiments.

Pallet Transfer between Pallet Elevator, Dual Loadlock, and Process Chamber

FIGS. 51-58 illustrate the pallet transfer process back and forth between the pallet elevator and dual loadlock, and back and forth between the dual loadlock and the process chamber in the first embodiment.

Pallet Disassembly and FPDS Removal from Pallet Elevator

FIGS. 59-63 describe the following: disassembly of two pallets within the pallet elevator, then removal of FPDSs from the pallet elevator into the FPD fab. The process for insertion of FPDSs for testing, then pallet reassembly, is the reverse: FIGS. 63-59. The process shown applies only to the first embodiment.

Timing Diagram for the First Embodiment of an FPDS Testing System

FIG. 64 is a timing diagram for the first embodiment of the present invention describing the 240 s cycle during which four FPDSs are fully tested by the multiple e-beam column assembly within the process chamber.

Second Embodiment of an FPDS Testing System

FIGS. 65-70 describe a second embodiment of the present invention, comprising two subsystems: a dual loadlock and a process chamber. The functions provided by both the pallet elevator and the dual loadlock in the first embodiment are combined into the dual loadlock in the second embodiment. This saves FPD fab floor space which is typically at a premium. The process chamber for the second embodiment is identical to that of the first embodiment.

Timing Diagram for the Second Embodiment of an FPDS Testing System

FIG. 70 is a timing diagram for the second embodiment of the present invention describing the 240 s cycle during which four FPDSs are fully tested by the multiple e-beam column assembly within the process chamber.

5 Schematic View of the Electron Optical Column and Detector Optics

FIG. 71 is a schematic cross-section of one of the electron optical columns 1211 and the corresponding detector 1240 shown in FIG. 2. Details of the electron source, focusing lenses, beam blanker, and deflectors are shown.

BRIEF DESCRIPTION OF THE FIGURES

10 FIG. 1 is a schematic of certain functional elements of a prior art multiple electron beam FPDS testing system;

FIG. 2 is a schematic 99 of certain functional elements of a multiple electron beam FPDS testing system according to the present invention;

FIG. 3 is a schematic isometric view of a pallet 100;

15 FIG. 4 is a schematic top view of pallet 100 in FIG. 3;

FIG. 5 is a schematic side view of pallet 100 in FIG. 3;

FIG. 6 is a schematic end view of pallet 100 in FIG. 3;

FIG. 7 is a schematic bottom view of pallet 100 in FIG. 3;

FIG. 8 is a schematic view through section A-A of pallet 100 in FIG. 4;

20 FIG. 9 is a schematic view through section E-E of pallet 100 in FIG. 7;

FIG. 10 is a schematic diagram of the circuits within pallet 100, external communication circuits to/from pallet 100, and an inductive power transfer system;

FIG. 11 is a schematic diagram of the circuits within pallet 100, external communication circuits to/from pallet 100, and a radiative power transfer system;

25 FIG. 12 is a schematic diagram of the circuits within pallet 100, external communication circuits to/from pallet 100, and a dual roller power transfer system;

FIG. 13 is a schematic view through section B-B showing the internal power system of pallet 100 in FIG. 6;

30 FIG. 14 is a schematic view through section F-F showing the internal power system of pallet 100 in FIG. 4;

FIG. 15 is a schematic view through section C-C showing the internal data bus of pallet 100 in FIG. 6;

FIG. 16 is a schematic view through section D-D showing the connections between the internal drive electronics and the FPD test pads on the FPDS within pallet 100 in FIG. 6;

FIG. 17 is schematic detail view 121 of contactors 425 connecting to FPD test pads 426 on FPDS 120 within pallet 100 in FIG. 3;

FIG. 18 is a schematic isometric view of pallet 100 and pin plate 202, illustrating the insertion direction for pin plate 202 into pallet 100;

FIG. 19 is a schematic top view with a partial cutaway of pallet 100 and pin plate 202 in FIG. 18;

FIG. 20 is a schematic side view of pallet 100 and pin plate 202 in FIG. 18;

FIG. 21 is a schematic end view of pallet 100 and pin plate 202 in FIG. 18;

FIG. 22 is a schematic isometric view of a robot end effector;

FIG. 23 is a schematic top view of the robot end effector in FIG. 22;

FIG. 24 is a schematic side view of the robot end effector in FIG. 22;

FIG. 25 is a schematic end view of the robot end effector in FIG. 22;

FIG. 26 is a schematic isometric cutaway view of pallet 100 and pin plate 202 in FIG. 18 showing pin plate 202 disassembling pallet 100;

FIG. 27 is a schematic view through section J-J of pallet 100 and pin plate 202 in FIG. 19 showing pin plate 202 before insertion into pallet 100;

FIG. 28 is a schematic view through section J-J of pallet 100 and pin plate 202 in FIG. 19 showing pin plate 202 inserted into pallet 100, positioned to separate pallet top 110 from pallet bottom 112;

FIG. 29 is a schematic view through section J-J of pallet 100 and pin plate 202 in FIG. 19 showing pin plate 202 inserted into pallet 100, positioned to separate FPDS 120 from pallet bottom 112;

FIG. 30 is a schematic view through section J-J of pallet 100 and pin plate 202 in FIG. 19 showing pin plate 202 fully inserted into the separated pallet;

FIG. 31 is a schematic view through section J-J of pallet 100 and pin plate 202 in FIG. 19 showing a robot end effector entering the separated pallet underneath FPDS 120;

FIG. 32 is a schematic view through section J-J of pallet 100 and pin plate 202 in FIG. 19 showing the robot end effector lifting FPDS 120 off pin plate 202;

FIG. 33 is a schematic view through section J-J of pallet 100 and pin plate 202 in FIG. 19 showing the robot end effector removing FPDS 120 from the separated pallet;

FIG. 34 is schematic detail view 122 showing capacitive sensor 1002 detecting the location of passivated alignment mark 1001 on FPDS 120 in FIG. 3;

FIG. 35 is a schematic view of capacitive sensor 1002 and its associated electronics;

FIG. 36 shows alignment mark 1034 underneath capacitive sensor 1002 in the case of FPDS misalignment;

FIG. 37 shows alignment mark 1034 underneath capacitive sensor 1002 in the case of correct FPDS alignment;

FIG. 38 is schematic detail view 123 of an optical sensor detecting the location of passivated alignment mark 1001 on FPDS 120 in FIG. 3;

FIG. 39A is a schematic view of X-Y-Yaw relative motion vectors between the pallet top 110 and pallet bottom 112 for alignment of contactors 425 with pads 426 as shown in FIG. 17;

FIG. 39B is detail view 1155 with partial cutaway of X-Y-Yaw actuators mounted between pallet top 110 and pallet bottom 112 in FIG. 39A;

FIG. 40 is a schematic detail view 124 of a locking mechanism between pallet top 110 and pallet bottom 112 in pallet 100 in FIG. 3;

FIG. 41 is a top view of a first embodiment of an FPDS testing system embodying the present invention, including pallet elevator 629, dual loadlock 575 and process chamber 522;

FIG. 42 is a side view of the FPDS testing system in FIG. 41;

FIG. 43 is a schematic view through section H-H of the FPDS testing system (pallet elevator not shown) in FIG. 41;

FIG. 44 is a schematic view through section G-G of the FPDS testing system in FIG. 42;

FIG. 45 is a schematic view through section G-G of the FPDS testing system (pallet elevator and transfer rollers not shown) in FIG. 42 showing a method for

measurement of the X-Y-Yaw position of pallet **572** within process chamber **522** – pallet **572** is shown mostly within dual loadlock **575**;

FIG. **46** is a schematic view through section G-G of the FPDS testing system (pallet elevator and transfer rollers not shown) in FIG. **42** showing pallet **572** half way
5 into process chamber **522**;

FIG. **47** is a schematic view through section G-G of the FPDS testing system (pallet elevator and transfer rollers not shown) in FIG. **42** showing pallet **572** mostly within process chamber **522**;

FIG. **48** is a schematic view through section G-G of the FPDS testing system
10 (pallet elevator and transfer rollers not shown) in FIG. **42** showing pallet **600** with an offset from its desired position **601** along the X-axis **573**;

FIG. **49** is a schematic view through section G-G of the FPDS testing system (pallet elevator and transfer rollers not shown) in FIG. **42** showing pallet **603** with an offset from its desired position **604** along the Y-axis **574**;

FIG. **50** is a schematic view through section G-G of the FPDS testing system
15 (pallet elevator and transfer rollers not shown) in FIG. **42** showing pallet **606** with Yaw (rotation about a vertical axis) **608** from its desired orientation **607**;

FIG. **51** is a schematic view through section H-H of the FPDS testing system in FIG. **41** showing an FPDS in pallet **600** from upper loadlock **502** being tested
20 while processed pallet (i.e., a pallet containing an already-tested FPDS) **602** is being removed from lower loadlock **505** into pallet elevator **629**;

FIG. **52** is a schematic view through section H-H of the FPDS testing system in FIG. **41** showing an FPDS in pallet **600** from upper loadlock **502** being tested while pallet elevator **629** is indexing to enable insertion of unprocessed pallet (i.e., a
25 pallet containing an FPDS ready for testing) **604** from pallet elevator **629** into lower loadlock **505**;

FIG. **53** is a schematic view through section H-H of the FPDS testing system in FIG. **41** showing an FPDS in pallet **600** from upper loadlock **502** being tested while unprocessed pallet **604** is being inserted from pallet elevator **629** into lower
30 loadlock **505**;

FIG. **54** is a schematic view through section H-H of the FPDS testing system in FIG. **41** showing an FPDS in pallet **600** from upper loadlock **502** being tested while pallet elevator **629** is indexing to enable removal of processed pallet **603**;

FIG. 55 is a schematic view through section H-H of the FPDS testing system in FIG. 41 showing an FPDS in pallet 600 from upper loadlock 502 being tested while processed pallet 603 is being removed from lower loadlock 505 into pallet elevator 629;

5 FIG. 56 is a schematic view through section H-H of the FPDS testing system in FIG. 41 showing an FPDS in pallet 600 from upper loadlock 502 being tested while pallet elevator 629 is indexing to enable insertion of unprocessed pallet 605 from pallet elevator 629 into lower loadlock 505;

10 FIG. 57 is a schematic view through section H-H of the FPDS testing system in FIG. 41 showing an FPDS in pallet 600 from upper loadlock 502 being tested while unprocessed pallet 605 is being inserted from pallet elevator 629 into lower loadlock 505;

15 FIG. 58 is a schematic view through section H-H of the FPDS testing system in FIG. 41 showing an FPDS in pallet 604 from lower loadlock 505 being tested while processed pallet 600 is being removed from upper loadlock 502 into pallet elevator 629

FIG. 59 is a schematic side view of the FPDS testing system in FIG. 42 with a cutaway showing two assembled pallets 701 and 702 in pallet elevator 629;

20 FIG. 60 is a schematic side view of the FPDS testing system in FIG. 42 with a cutaway showing two disassembled pallets in pallet elevator 629;

FIG. 61 is a schematic side view of the FPDS testing system in FIG. 42 with a cutaway showing a three-blade robot entering pallet elevator 629;

25 FIG. 62 is a schematic side view of the FPDS testing system in FIG. 42 with a cutaway showing the three-blade robot lifting two tested FPDSs 721 and 724 off two pin plates 705 and 706, respectively;

FIG. 63 is a schematic side view of the FPDS testing system in FIG. 42 with a cutaway showing the three-blade robot removing two tested FPDSs 721 and 724 from pallet elevator 629;

30 FIG. 64 is an operational cycle timing diagram for the FPDS testing system in FIGS. 41 and 42;

FIG. 65 is a schematic top view of a second embodiment of an FPDS testing system;

FIG. 66 is a schematic side view of the FPDS testing system in FIG. 65;

FIG. 67 is a schematic view through section K-K of the FPDS testing system in FIG. 65 showing an FPDS in pallet 807 from upper loadlock 800 being tested while a two-blade robot is entering lower loadlock 800;

FIG. 68 is a schematic view through section L-L of the FPDS testing system in
5 FIG. 66;

FIG. 69 is a schematic view through section K-K of the FPDS testing system in FIG. 65 showing an FPDS in pallet 907 from lower loadlock 801 being tested while the two-blade robot is entering upper loadlock 800; and

FIG. 70 is an operational cycle timing diagram for the FPDS testing system in
10 FIGS. 65 and 66.

FIG. 71 is a schematic cross-section of one of the electron optical columns 1211 and the corresponding detector 1240 shown in FIG. 2.

DETAILED DESCRIPTION

FIG. 2 is a schematic 99 of certain functional elements of a multiple electron
15 beam system for testing substrates. Although the present invention applies to various types of substrates requiring electrical testing, the following disclosure describes in detailed example a FPDS testing system according to the present invention. To avoid the disadvantages of a probe frame which were discussed in reference to FIG. 1, FPDS 120 (which may have a plurality of FPDs, such as six
20 FPDs in the FPDS shown in FIG. 2) is carried in a pallet 100 which provides the following benefits during the operation of an FPDS testing system 99 according to the present invention:

- 1) Pallet 100 supports and protects the delicate FPDS 120 during transport and e-beam testing within the process chamber (not shown) –
25 this support virtually eliminates the chance of FPDS breakage in the system which would lead to unplanned tool downtime. In the prior art, the FPDS alone is transported through the testing system with no protection against breakage.
- 2) The pallet 100 supplies electrical connections to the FPDS under test –
30 if a contactor within the pallet fails, the pallet can be replaced with no need to vent and open a process chamber of the present invention,

which will be described in reference to the figures of the drawing. There is also no impact on either throughput or tool availability.

- 3) The pallet **100** contains internal alignment mechanisms which enable the pallet contactors to be accurately aligned to all of the test pads on the FPDS **120** with no impact on throughput – see FIGS. **39A-39B** (this is accomplished by performing the alignment step outside the process chamber, while another FPDS is being tested).
- 4) The pallet **100**, in conjunction with a linear array of e-beams spanning the full width of the FPDS, eliminates the need for an X-Y stage, thereby substantially reducing system cost and increasing reliability.
- 5) If there is a change in the FPDS design, a new pallet (with different connections to the test pads, if necessary) can be substituted with no effect on either throughput or tool availability.
- 6) Since the pallet **100** interacts with the FPDS testing system using wireless communication, all moving cables are eliminated, improving reliability.
- 7) The FPDS testing system can use pallets containing FPDSs of different sizes as long as the outer dimensions of the pallets are the same – there is no system downtime for the conversion. This capability enables the system design to have increased extensibility to future FPDS generations.

Pallet **100** is supported by bi-directional motor-driven rollers **627** to transport pallet **100** into and out of the process chamber (not shown) along direction **1299**.

Each column **1211** includes an electron source for generating an electron beam **1230**, one or more lenses for focusing electron beam **1230** onto the surface of FPDS **120**, and a deflector for deflecting electron beam **1230** on the surface of FPDS **120**. The design of columns **1211** is optimized to scan beams **1230** substantially along an axis perpendicular to the direction of travel **1299** (X direction) of pallet **100**. FIG. **71** is a schematic cross-section of one of the electron optical columns **1211** and the corresponding detector **1240** shown in FIG. **2**. Details of the e-beam testing process applicable to the present invention are discussed in U.S. Patent Application Ser. No. 11/225,376 filed September 12, 2005 incorporated by reference herein.

In FIG. 2, five electron beam columns **1211** generate electron beams **1230**, each beam **1230** being configured to scan substantially along an axis perpendicular to the direction of travel **1299** of pallet **100**. The scan distance of each beam **1230** is typically ~125 mm wide and the spacing of columns **1211** is less than or equal to the width of the beam scans, thus neighboring scans overlap or abut, enabling the full width of FPDS **120** to be scanned with at least one e-beam **1230** without the need for motion in the Y direction. This allows the entire X-Y surface of FPDS **120** to be scanned using motion along only one axis **1299** (X axis), with pallet **100** supported and moved by the set of bi-directional motor-driven rollers **627**.

As for the prior art in FIG. 1, the impact of the electron beams **1230** with FPDS **120** causes the emission of secondary electrons (SEs) and backscattered electrons (BSEs). Signal electrons **1244** may comprise only SEs, only BSEs, or a mixture of SEs and BSEs. The detector optics design is configured to ensure that the signal electrons **1244** from each beam **1230** are collected only by the detector **1240** associated with that particular beam **1230** in order to avoid cross-talk between pixel test signals. Details of the detector optics design and operation applicable to the present invention are discussed in U.S. Patent Application Ser. No. 11/093,000 filed March 28, 2005 and in U.S. Patent Application Ser. No. 11/355,256 filed February 14, 2006, both incorporated by reference herein.

The FPDS testing system of the present invention in FIG. 2 utilizes a different method for measuring and controlling the position of FPDS **120** under testing e-beams **1230** than is used in the prior art of FIG. 1. Position sensors **550-553** emit laser beams **568-571**, respectively, toward the reflective sides of pallet **100**. The laser beams are then reflected off the sides of pallet **100** back to each sensor **550-553**, respectively (i.e., with no crosstalk between sensors **550-553**). Sensors **550-553** may employ various methods of determining the distances from each sensor to the reflective sides of pallet **100**, including laser interferometry, laser beam triangulation, or some other method for distance determination – the accuracy of the X-Y-Yaw position measurements preferably should be in the ~2-10 μm range, substantially smaller than the dimensions of the test pads on the FPDS **120**. The respective distances from each of sensors **550-553** to pallet **100** can then be used to accurately determine the pallet X-Y-Yaw position as is familiar to those skilled in the

art. Details of the pallet X-Y-Yaw position sensing methodology are given in FIGS. 45-50, below.

System control **1203** sends control signals along data line **498** to data transmitter **554** which transmits signal beam **556** to data receiver **442** mounted in the side of pallet **100**. Pallet **100** communicates with system control **1203** using data transmitter **440** (mounted in the side of pallet **100**) to transmit signal beam **557** to data receiver **555**. The signal from data receiver **555** passes along data line **499** to system control **1203**.

The signals being transmitted from system control **1203** to pallet **100** include the following:

- 1) Data on the X-Y-Yaw position of pallet **100** relative to optics assembly **520** (first embodiment) or **806** (second embodiment). The pallet uses this data to determine which pixels are within range of beams **1230**, and therefore which test pads should have voltages sent to them for activating the thin-film transistors which drive the pixel elements to be tested.
- 2) Confirmation of status information received – this allows pallet **100** to verify that system control **1203** received the correct status information.
- 3) Control information for when to activate battery charger **406** (FIG. 10), **471** (FIG. 11), or **482** (FIG. 12).
- 4) Any other necessary control information needed by internal drive electronics **410**.

The signals being transmitted from pallet **100** to system control **1203** include the following:

- 1) Confirmation of X-Y-Yaw data received – this allows system control **1203** to verify that pallet **100** received the correct X-Y-Yaw data.
- 2) Status information on internal drive electronics **410** and the charge state of battery **408**.

Signal beams **556** and **557** may be any form of radiation capable of being modulated with the control data, such as radio waves, IR, visible light, or UV. An important advantage of the present invention over the prior art is the complete elimination of cables and cable connectors between system control **1203** and the FPDS **120** under test which is moving along direction **1299** within the process

chamber (not shown). The elimination of cables and cable connectors leads to higher throughput (since the speed of pallet **100** is not limited by the cables) and increased reliability.

Cables **1212** connect columns **1211** to optics control **1201**. Cables **1241** connect detectors **1240** to detectors control **1242**. Data lines **1210** connect position sensors **550-553** to X-Y-Yaw readout **1202**. Cables **1225** connect bi-directional motor-driven rollers **627** to rollers control **1200**. Controls **1200-1202** and **1242** are connected to system control **1203** by control links **1226**, **1220**, **1219**, and **1243**, respectively.

FLAT PANEL DISPLAY SUBSTRATE PALLET DESIGN

FIG. **3** is a schematic isometric view of a pallet **100**. Pallet **100** includes pallet top **110** and pallet bottom **112**, with provision for an FPDS **120** to be clamped between them. Typically, multiple flat panel displays (FPDs) will be fabricated on a single FPDS **120** – pallet top **110** is configured with cross-members **114** and **116** which cover areas on FPDS **120** which are not to be tested or otherwise processed, but which typically contain test pads connecting to shorting bars as discussed in FIG. **1**. Detail view **121** shows contactors making electrical connections with test pads on FPDS **120** (see FIG. **17**). Detail view **122** shows a capacitive sensor locating an alignment mark on FPDS **120** (see FIGS. **34-37**). Detail view **123** shows an optical sensor locating an alignment mark on FPDS **120** (see FIG. **38**). Detail view **124** shows a locking mechanism between pallet top **110** and pallet bottom **112**.

FIGS. **4-7** are schematic top, side, end and bottom views, respectively, of pallet **100** in FIG. **3**. In the top view in FIG. **4**, the overall X-Y pallet dimensions **130** and **132** are shown. Also shown is outline **146** of FPDS **120**. The X-Y dimensions of pallet **100** must be somewhat larger than the X-Y dimensions of FPDS **120** in order to accommodate internal drive electronics **410** within pallet **100** (see FIGS. **13-16**). Clearly, pallets with the same overall dimensions **130** and **132** can accommodate any generation FPDS which has the same size as outline **146**, or is smaller than outline **146** – this is a key advantage of the present invention relative to the prior art: a single FPDS testing system can test multiple FPDS generations with no need for any system hardware modifications. As long as the system is designed to handle sufficiently large pallets, a number of FPDS generations can be accommodated with

a single FPDS testing system. For example, a "Gen-9" tool is fully capable of testing "Gen-8" or "Gen-7" FPDSs with no tool downtime for conversion. Any changes to the e-beam testing procedure required when converting between FPDS generations can be done entirely within system control **1203** which drives the test signals to/from
 5 pallet **100** – these changes would typically involve software modifications only. Often, even within a given FPDS generation, the layout of test pads and/or alignment marks on the FPDS can change – with the present invention, only modifications to the pallet top would be required (to reconfigure the positions of contactors and/or alignment mark detectors) which can be done off-line from system operation, and
 10 thus would have no effect on either system throughput or system availability (i.e., there is no downtime for changing the probe frame).

Dimensions **134** and **136** show the distances along the X-axis (horizontal in FIG. **4**) from outline **146** to the sides of pallet **100**. Dimensions **138** and **140** are the distances along the Y-axis (vertical in FIG. **4**) from outline **146** to the sides of pallet
 15 **100**. The openings for each FPD on FPDS **120** have dimensions **142** (along the X-axis) and **144** (along the Y-axis). Here, all the FPDs on the FPDS **120** are assumed to have the same size, however this is not mandatory for the pallet concept. Cross-members **114** and **116** extend across areas of FPDS **120** between the individual FPDs, and may contain contactors for electrical connection to test pads on FPDS
 20 **120** (see FIG. **17**). Cross-sections A-A and F-F through pallet **100** are also illustrated in FIG. **4**.

In the side view of pallet **100** shown in FIG. **5**, pallet height **139** is exaggerated relative to the (horizontal) X-axis dimension. The heights of pallet top **110** and pallet bottom **112** stack up to generate pallet height **139**.

25 FIG. **6** is an end view of pallet **100**, again showing the stacking of pallet top **110** and pallet bottom **112**. Data receiver **442** and data transmitter **440** are visible, as well as cross-sections B-B, C-C and D-D.

FIG. **7** is a schematic bottom view of pallet **100** in FIG. **3**. At least three holes **164** (seven shown) penetrate pallet bottom **112** to permit passage of long pins **204**
 30 (see FIG. **28**) – note that holes **164** must be outside outline **146** in order to prevent long pins **204** from striking FPDS **120**. A multiplicity of holes **166** also penetrate pallet bottom **112** to permit passage of short pins **206** (see FIG. **29**) – note that holes **166** must be within outline **146** to ensure that short pins **206** will lift FPDS **120**.

Holes **164** are at distances **150** and **152** from the four corners of pallet bottom **112** and three other holes **164** are spaced midway along three sides of pallet bottom **112**. It is not necessary to place a hole **164** in the left side of pallet bottom **112** since there is no corresponding long pin **204** on the left side of the pin plate (see FIG. **18**). The exact number and placement of holes **164** (and the corresponding pins **204** in pin plate **202**) is not critical to the pallet disassembly operation (see FIGS. **27-30**) – it is only important to have sufficient holes **164** (and long pins **204**) to lift pallet top **110** without slippage or instability without interfering with the ability to insert a robot end effector between pallet top **110** and pallet bottom **112** during FPDS removal/insertion (see FIGS. **31-33**). The X-Y spacings **160** and **162**, respectively, of holes **166** must be close enough to ensure minimal sagging of an FPDS between pins **206** as explained in FIG. **30**. Cross-section E-E is also illustrated in FIG. **7**.

FIG. **8** is a schematic view through section A-A of pallet **100** in FIG. **4** with dimensions perpendicular to FPDS **120** exaggerated. Pallet top **110** has a downward-facing lip which enables pallet top **110** to clamp FPDS **120** (shown exaggerated in thickness) down against the upper center surface of pallet bottom **112**. For proper operation of the alignment procedure shown in FIGS. **39A-39B**, it is preferred that the upper surface **129** of pallet bottom **112** (which comes into contact with the undersurface of FPDS **120**) have sufficient friction to prevent slippage between FPDS **120** and pallet bottom **112** when pallet top **110** is being moved relative to pallet bottom **112**. Pallet top **110** fits loosely over pallet bottom **112** to allow for small X-Y-Yaw displacements of pallet top **110** relative to pallet bottom **112** in order to align contactors **425** in pallet top **110** with test pads **426** (see FIG. **17**) on FPDS **120** (see FIGS. **39A-39B**). Openings **111** contain internal drive electronics and wiring necessary for electrical biasing of FPDS **120** (see FIGS. **13-16**). Cross-members **116** may also contain wiring (not shown) allowing for additional contactors along the Y-axis edges of the FPDs on the FPDS.

FIG. **9** is a schematic view through section E-E of pallet **100** in FIG. **7**, with dimensions perpendicular to FPDS **120** exaggerated. Openings **111** contain internal drive electronics and wiring necessary for electrical biasing of the FPDS **120** (see FIGS. **13-16**). Openings **113** in cross-members **114** contain wiring (not shown) connecting to contactors **425** (see FIG. **16**). Holes **164** and **166** penetrate pallet

bottom 112 to permit passage of pins 204 and 206, respectively, on pin plate 202 (see FIGS. 28-29).

INTERNAL STRUCTURE AND ELECTRONICS OF THE PALLET

FIG. 10 is a schematic diagram of the electronics within pallet 100, data circuits to/from pallet 100, and an inductive power transfer system. Pallet 100 contains internal drive electronics 410 which provides control voltages through control lines 423 to contactors 425. These control voltages bias the source and gate connections to the TFTs on the FPDS as is familiar to those skilled in the art of FPDS testing – see U.S. Patent Application Ser. No. 11/225,376 filed September 12, 2005 incorporated by reference herein.

Contactors 425, which typically can be “POGO” pins or some other type of spring-loaded contactor, make contact with test pads 426 on the surface of FPDS 120. Test pads 426 are connected to shorting bars (not shown) on FPDS 120 by traces 427. Control of internal drive electronics 410 is effected through a first data link comprising data line 498 from system control 1203 (see FIG. 2), data transmitter 554, signal beam 556, data receiver 442, and input signal line 430. Internal drive electronics 410 communicates with system control 1203 (see FIG. 2) by means of a second data link comprising output data line 431, data transmitter 440, signal beam 557, data receiver 555, and data line 499 to system control 1203 (see FIG. 2). Internal data bus 422 includes signal lines 430 and 431.

Internal drive electronics 410 are powered through an inductive power transfer system (IPTS) wherein the components outside pallet 100 comprise ac power supply 400 and primary transformer coil 402 which may be mounted within dual loadlock 575 and/or within pallet elevator 629 (first embodiment - see FIGS. 41-44) or within dual loadlock 899 (second embodiment - see FIGS. 65-66). The components of the IPTS within pallet 100 comprise secondary transformer coil 404, battery charger 406, wires 420 to charge battery 408, and pallet dc power lines 421 to internal drive electronics 410. Internal drive electronics 410 are powered by battery 408 at all times, but battery 408 is recharged only when pallet 100 is out of process chamber 522 (FIGS. 41-42), or out of process chamber 804 (FIGS. 65-66). It is desirable to maximize the magnetic flux coupling efficiency between primary coil 402 and secondary coil 404 to minimize the amount of stray magnetic flux which can have a

negative effect on the operation of columns **1211** in FIG. **2**. Methods of maximizing the flux coupling are well known to those skilled in the art. One such method is the use of a first core inside coil **402** with two pole faces positioned opposite two pole faces in a second core inside coil **404**. Magnetic shielding can be placed around coils **402** and **404** to reduce stray magnetic field generation further.

FIG. **11** is a schematic diagram of the electronics within pallet **100**, data circuits to/from pallet **100**, and a radiative power transfer system. All data links and connections are the same as for FIG. **10**. FIG. **11** differs from FIG. **10** only in the use of a radiative power transfer system (RPTS) to charge battery **408**. Light transmitter **479** radiates a strong light beam **478** to photocell **497** mounted on the exterior of pallet **100**. Photocell **497** generates a dc current which is fed through wires **470** to battery charger **471**, which charges battery **408** through wires **472**. The main advantage of an RPTS over the IPTS in FIG. **10** is the lack of stray magnetic field generation which could allow the RPTS to operate within process chamber **522** (FIGS. **41-42**) or process chamber **804** (FIGS. **65-66**). The main disadvantage of the RPTS is potentially less efficient power transfer due to the relatively low efficiency of photocells relative to transformers.

FIG. **12** is a schematic diagram of the electronics within pallet **100**, data circuits to/from pallet **100**, and a dual roller power transfer system. All data links and connections are the same as for FIGS. **10** and **11**. FIG. **12** differs from FIGS. **10** and **11** only in the use of a dual roller power transfer system (DRPTS) to charge battery **408**. Power supply **489** supplies an ac or a dc voltage difference through wires **484** to rollers **487** and **488** which roll along two contact strips **485** and **486**, respectively, on the exterior of pallet **100**. The voltage difference picked up between power strips **485** and **486** is fed through wires **483** to battery charger **482**, which charges battery **408** through wires **480**. The main advantage of a DRPTS over the IPTS in FIG. **10** is the lack of stray magnetic field generation which could allow the RPTS to operate within the process chamber. The main disadvantage of the DRPTS is the need for physical contact to pallet **100** which may involve reliability issues, in particular relating to the need to keep the contact strips **485** and **486** and rollers **487** and **488** clean enough to provide good electrical contact. A variant of the configuration shown in FIG. **12** would place rollers **487** and **488** on pallet **100** and contact strips **485** and **486** outside pallet **100**.

FIG. 13 is a schematic view through section B-B in FIG. 6 showing the inductive power transfer system from FIG. 10. External ac power supply 400 drives primary transformer coil 402. The magnetic field generated by coil 402 passes through secondary coil 404, thereby generating an ac voltage which is conducted to battery charger 406 which rectifies the ac voltage to a dc voltage used to charge battery 408 through connections 420. Battery 408 powers internal drive electronics 410 by means of power circuit 421. It is important that power connections 421 be coaxial cables or twisted pairs to avoid the generation of external magnetic fields during FPDS testing. Primary coil 400 can be mounted in pallet elevator 629 and/or dual loadlock 575 (first embodiment – FIGS. 41-42) or dual loadlock 899 (second embodiment – FIGS. 65-66) and would be used only when the pallet is not in either process chamber 522 (FIGS. 41-42) or process chamber 804 (FIGS. 65-66) – this avoids possible problems with the ac magnetic field between coils 402 and 404 potentially deflecting the electron beams used for FPDS testing. A preferred embodiment would include two iron cores, one within coil 402 and the other core within coil 404 with opposing pole faces to minimize field leakage. This method is familiar to those skilled in the art. Alternative methods of transferring power to the pallet are possible, as described in FIGS. 11 and 12. The key requirement is that all transfer of power to the pallet must cause no negative effects on the FPDS testing process – this requires a battery on-board the pallet to power the internal drive electronics 410 between charging cycles. Since the pallet is exposed to vacuums in the loadlock and process chamber in the range of $\sim 10^{-6}$ torr, it is necessary that battery 408 and internal drive electronics 410 be vacuum compatible (i.e., demonstrate minimal outgassing) and also that battery 408 not explode or be damaged due to internal pressure when in the vacuum. The X-Y dimensions 130 and 132 (FIG. 4) of pallet 100 must be larger than the X-Y dimensions of FPDS 100 in order to accommodate battery charger 406, battery 408, and internal drive electronics 410, which are housed in opening 111 around the perimeter of pallet top 110 as shown. To simplify the figure, the internal data bus and connections between internal drive electronics 410 and pallet 100 are not shown in FIGS. 13 and 14 (see FIGS. 15 and 16).

FIG. 14 is a schematic view through section F-F in FIG. 4 of pallet 100 showing the internal power system of pallet 100 in FIG. 10. All of the electronics shown in FIGS 13-16 is in pallet top 110.

FIG. 15 is a schematic view through section C-C showing the internal data bus of pallet 100 in FIG. 6. Data receiver 442 is a sensor for whatever type of radiation is used for beam 556 (FIG. 10). Similarly, data transmitter 440 is a sensor for whatever type of radiation is used for beam 557 (FIG. 10). Both data receiver 442 and data transmitter 440 are used to communicate between system control 1203 (FIG. 2) and pallet 100 as illustrated in FIGS. 2 and 10-12. Communication between data receiver 442, data transmitter 440 and internal drive electronics 410 is by way of internal data bus 422, contained in channel 111, which must not generate any external magnetic fields that could affect the electron beams used for FPDS testing. In addition, internal data bus 422 must be immune to external RF interference.

FIG. 16 is a schematic view through section D-D showing connections 423 between internal drive electronics 410 and contactors 425 within pallet 100 in FIG. 6. For clarity, contactors 425 are shown outside cross-members 114 – in reality, contactors 425 would be inside cross-members 114 (see FIG. 17) and inside the outer perimeter of pallet top 110. Additional contactors (not shown) could also be within cross-members 116. Pallet 100 must be fabricated to provide adequate stiffness to assure that all contactors 425 make good electrical contact with test pads 426 on FPDS 120 – if POGO pins are used for contactors 425, each pin will exert an upward force on pallet top 110 of at least a few g (force), adding up to sizeable total upward forces in the case of large numbers of POGO pins.

FIG. 17 is schematic detail view 121 with cutaway 428 showing contactors 425 within pallet 100 connecting to test pads 426 on FPDS 120 in FIG. 3. As shown in FIGS. 10-12 and 16, the voltages on contactors 425 are driven by internal drive electronics 410 within pallet top 110. Contactors 425 are spring-loaded downwards against test pads 426, typically with forces of at least a few g. Test pads 426 connect to traces 427, which in turn connect to shorting bars (not shown) on FPDS 120 as explained in FIG. 1. The design of pallet 100 implements a one-to-one mapping between contactors 425 in pallet top 110 and test pads 426 on FPDS 120. Precise alignment of contactors 425 with test pads 426 is desirable in order to preserve this one-to-one mapping so that all test pads 426 receive the necessary

bias voltages – the procedure illustrated in FIGS. 34-39B implements a procedure to accomplish contactor-to-test pad alignment across the entire surface of FPDS 120 simultaneously.

PIN PLATE AND ROBOT END EFFECTOR DESIGN

5 FIG. 18 is a schematic isometric view of pallet 100 and pin plate 202, illustrating the insertion direction 208 for pin plate 202 to enter pallet 100. Pallet 100 is comprised of pallet top 110 and pallet bottom 112, with provision for FPDS 120 to be clamped between them. As is shown in detail in FIGS. 27-30, long pins 204 fit through holes 164 in pallet bottom 112 (see FIG. 7) to lift pallet top 110 off FPDS 120
10 and off pallet bottom 112. Similarly, short pins 206 fit through holes 166 in pallet bottom 112 (see FIG. 7) to lift FPDS 120 off pallet bottom 112.

 FIGS. 19-21 are schematic top, side and end views of pallet 100 and pin plate 202 in FIG. 18, respectively. FIG. 19 has a partial cutaway to show pin plate 202 beneath pallet 100. In FIGS. 20 and 21, the vertical scales (perpendicular to the
15 plane of pallet 100) of both pallet 100 and pin plate 202 are exaggerated for clarity. The locations of pins 204 and 206 must match the locations of holes 164 and 166 (see FIG. 7), respectively. The diameters of pins 204 and 206 should be large enough to prevent bending or buckling when supporting the weights of pallet top 110 and FPDS 120, respectively (see FIG. 30). The diameters of holes 164 and 166
20 (see FIG. 7) should allow some clearance with pins 204 and 206, respectively, to enable X-Y-Yaw alignment of pallet top 110 with pallet bottom 112, as shown in FIGS. 39A-39B. The lengths 288 of pins 206 must be sufficient to raise FPDS 120 far enough above pallet bottom 112 to allow room for robot end effector 243 (see FIG. 31) to fit between FPDS 120 and pallet bottom 112. The lengths 284 of pins
25 204 must be enough longer than the lengths 288 of pins 206 to allow FPDS 120 to be lifted off pins 206 by robot end effector 243 (see FIG. 32).

 FIG. 22 is a schematic isometric view of a robot end effector 243 attached to end effector mount 240. End effector 243 is equivalent to end effectors 731-733 (FIGS. 61-63) and end effectors 831-832 (FIGS. 67-69). End effector mount 240 is
30 equivalent to end effector mounts 730 (FIGS. 61-63) and 830 (FIGS. 67-69).

 FIG. 23 is a schematic top view of robot end effector 243 and end effector mount 240 in FIG. 22. End effector 243 is comprised of end effector bars 242 and

end effector bars connector **321**. Dimension **301** is preferably greater than the length of an FPDS to ensure that the FPDS is fully supported during FPDS transport. The purpose of slots **306** is to allow end effector **243** to fit between short pins **204** on pin plate **202** (see FIG. **19**). The widths **305** of slots **306** between end effector bars **242** must be larger than the diameters of short pins **206** but not so large that an FPDS can sag excessively between end effector bars **242**. The sum of the widths **304** and **305** must equal the Y-axis spacing of short pins **206** (which must match the Y-axis spacing **162** of holes **166** – see FIG. **7**).

FIG. **24** is a schematic side view of robot end effector **243** and end effector mount **240** in FIG. **22**. The thickness **306** of end effector **243** (which is the thickness of end effector bars **242**) must be adequate to prevent excessive sagging of end effector bars **242** under their own weight plus the weight of an FPDS being transported. "Excessive sagging" here is any amount of sagging which may result in damage to the FPDS being transported or which would interfere with the FPDS exchange process (see FIGS. **61-63** and **67-69**).

FIG. **25** is a schematic end view of robot end effector bars **242** and end effector mount **240** in FIG. **22**. Dimension **302** is preferably as wide as possible to give maximum support to the FPDS being transported while still fitting between long pins **204** along the two long sides of pin plate **202** (see FIG. **19**).

DETAILED PALLET DISASSEMBLY PROCEDURE

FIGS. **26-33** show various views of pin plate **202** disassembling a pallet. This process occurs within pallet elevator **629** in the first embodiment of the present invention shown in FIGS. **41** and **42**, and within dual loadlock **899** in the second embodiment shown in FIGS. **65** and **66**. Note that pin plate **202** is shown simplified – the trenches to allow clearance for the bi-directional motor-driven rollers are omitted for clarity, as are the rollers themselves.

FIG. **26** is a schematic isometric cutaway view of pin plate **202** disassembling a pallet (including pallet top **110** and pallet bottom **112**, with provision for FPDS **120** to be clamped between them). Cutaway **323** of pallet top **110** reveals internal spaces **111** and **113** for internal drive electronics **410** and wiring (not shown – see FIGS. **13-16**). Cutaway **322** of FPDS **120** reveals robot end effector **243** (attached to end effector mount **240**) supporting FPDS **120**. Cutaway **321** of robot end effector

243 (comprised of end effector bars **242** and end effector bars connector **321**) reveals pallet bottom **112** as well as short pins **206** and long pins **204** on pin plate **202** protruding through holes **166** and **164**, respectively (see FIG. 7), in pallet bottom **112**. At the upper right, a long pin **204** can be seen supporting the edge of pallet top **110**. Cutaway **320** in pallet bottom **112** reveals pin plate **202** underneath, showing a few short pins **206** and a long pin **204** at the corner of pin plate **202** at the center front in FIG. 26.

FIGS. 27-30 show the sequence of steps by which pin plate **202** disassembles pallet **100**, enabling already-tested FPDS **120** to be removed.

FIG. 27 is a schematic view through section J-J of pallet **100** and pin plate **202** in FIG. 19. Long pins **204** in pin plate **202** are aligned coaxially with, and ready for insertion into, holes **164** in pallet bottom **112**. Pin plate **202** starts moving upwards (arrow **210**) to begin the pallet **100** disassembly procedure.

FIG. 28 is a schematic view through section J-J of pallet **100** and pin plate **202** in FIG. 19. The pin plate actuator (not shown) has raised pin plate **202** to insert long pins **204** into holes **164**. The upper ends of long pins **204** are now making contact with undersurface **207** of pallet top **110**. Pallet **100** is still assembled at this point. Pin plate **202** continues moving upwards (arrow **212**).

FIG. 29 is a schematic view through section J-J of pallet **100** and pin plate **202** in FIG. 19. The pin plate actuator (not shown) has raised pin plate **202** an additional distance upwards from FIG. 28, lifting pallet top **110** off FPDS **120**. The upwards motion of pin plate **202** has also inserted short pins **206** into holes **166**. The upper ends of short pins **206** are now making contact with undersurface **216** of FPDS **120**. Pin plate **202** continues moving upwards (arrow **214**).

FIG. 30 is a schematic view through section J-J of pallet **100** and pin plate **202** in FIG. 19. The pin plate actuator (not shown) has raised pin plate **202** an additional distance upwards from FIG. 29, lifting pallet top **110** farther away from pallet bottom **112** – note that pallet top **110** is the same distance above FPDS **120** as in FIG. 29. The upwards motion of pin plate **202** has also lifted FPDS **120** off pallet bottom **112**. Upwards motion of pin plate **202** ceases at this point.

FIGS. 31-33 show the sequence of steps by which a robot, having an end effector **243** and end effector mount **240**, removes an already-tested FPDS **120** from a disassembled pallet. End effector **243** is equivalent to end effectors **731-733** in the

three-blade robot shown in FIGS. 61-63 or to end effectors 831-832 in the two-blade robot shown in FIGS. 67-69.

FIG. 31 is a schematic view through section J-J of pallet 100 and pin plate 202 in FIG. 19. End effector 243 is moving in (arrow 244) under FPDS 120 and above pallet bottom 112. It is important that spacing 299 between the under surface of FPDS 120 and the upper surface of pallet bottom 112 is wide enough to accommodate the thickness 306 (FIG. 24) of end effector 243 in order to avoid striking (and possibly damaging) FPDS 120 and/or pallet bottom 112.

FIG. 32 is a schematic view through section J-J of pallet 100 and pin plate 202 in FIG. 19. End effector 243 is moving up (arrow 246) to lift FPDS 120 off short pins 206 on pin plate 202. Relative lengths 284 and 288 of long pins 204 and short pins 206, respectively, (see FIG. 20) must be chosen to ensure adequate clearance for end effector 243 to lift FPDS 120 and exit from the disassembled pallet without dragging the upper surface of FPDS 120 along the under surface of pallet top 110, thereby possibly damaging FPDS 120 and/or pallet top 110.

FIG. 33 is a schematic view through section J-J of pallet 100 and pin plate 202 in FIG. 19. End effector 243 is withdrawing (arrow 250) FPDS 120 from the disassembled pallet.

The reverse process from that shown in FIGS. 27-33 is used to insert an FPDS 120 for testing into pallet 100:

- 1) FIG. 33: End effector 243 carries (arrow 250 reversed) FPDS 120 into disassembled pallet 100.
- 2) FIG. 32: End effector 243 lowers (arrow 246 reversed) FPDS 120 onto short pins 206 on pin plate 202.
- 3) FIG. 31: End effector 243 withdraws (arrow 244 reversed) from disassembled pallet 100.
- 4) FIG. 30: Pin plate 202 is ready to begin reassembling pallet 100.
- 5) FIG. 29: Pin plate 202 has lowered (arrow 214 reversed) FPDS 120 onto pallet bottom 112.
- 6) FIG. 28: Pin plate 202 has lowered (arrow 212 reversed) pallet top 110 onto FPDS 120 and onto pallet bottom 112, clamping FPDS 120 between pallet top 110 and pallet bottom 112.

- 7) FIG. 27: Pin plate 202 actuator has lowered (arrow 210 reversed) far enough to remove long pins 204 and short pins 206 completely from holes 164 and 166, respectively, in pallet bottom 112. At this point, pallet 100 has been reassembled, clamping an untested FPDS 120 between pallet top 110 and pallet bottom 112, ready for alignment of pallet top 110 to FPDS 120 (see FIGS. 34-39B), followed by e-beam testing.

PROCEDURE FOR ALIGNING THE PALLET TOP TO THE FPDS

FIG. 34 is a schematic detail view 122 showing a capacitive sensor 1002 attached to pallet top 110 detecting the location of a passivated alignment mark 1001 on FPDS 120 in FIG. 3. An FPDS has a number of alignment marks 1001, typically with a "+" shape. In order to make good electrical contact between the contactors 425 in pallet top 110 and test pads 426 on FPDS 120 (see FIG. 17), in general it will be necessary to adjust the position of pallet top 110 relative to FPDS 120. The upper center surface of pallet bottom 112 is made from a material, such as rubber, which prevents FPDS 120 from sliding relative to pallet bottom 112. Thus, if pallet top 110 is moved a certain amount relative to pallet bottom 112, it will move the same amount relative to FPDS 120. FIGS. 39A-39B illustrate a method for accomplishing relative motion between pallet top 110 and pallet bottom 112. It is not possible to make direct electrical connection to alignment mark 1001 because at this stage in the manufacturing of FPDS 120, alignment mark 1001 is already covered by an insulating passivation layer. Because what is important is the alignment between contactors 425 (which are part of pallet top 110) and test pads 426 (which are part of FPDS 120 – see FIG. 17), it is necessary to mount capacitive sensor 1002 on pallet top 110 so that the alignment mechanism shown in FIGS. 39A-39B serve to move both contactors 425 and capacitive sensor 1002 together.

FIG. 35 is a schematic view of capacitive sensor 1002 and its associated electronics, with detail 122 shown as an inset. Capacitive sensor 1002 is shown with 25 individual sensing elements 1011, in a 5 x 5 array. The electrical circuits shown connected to one sensing element 1011 are identical to circuits (not shown) which would be connected to the other 24 sensing elements. The method used here to detect the position of alignment mark 1001 is capacitive sensing of the underlying

passivated mark – the mark itself is made from conducting material, so it will have a small capacitance which can be sensed by each of the 25 sensing elements. In FIG. 35, alignment mark **1001** is shown aligned with capacitive sensor **1002** – thus the center of the “+” mark is under the center sensing element of the 5 x 5 array.

5 The square-wave relaxation oscillator circuit formed by op-amp **1013**, op-amp output **1021**, resistors **1014**, **1015**, and **1017**, capacitor **1018**, capacitance **1020** (arising from connection **1012** to sensing element **1011** and the ground connection **1019** to FPDS **120**), and summation node **1016** will be understood by those skilled in the art. In this oscillator, the voltage **1025** on output **1021** of op-amp **1013** swings
 10 back-and-forth between voltages near the op-amp **1013** power supply rails (not shown) at a frequency which is inversely proportional to the total capacitance of the parallel combination of capacitor **1018** and capacitance **1020** (the capacitance between sensing element **1011** and alignment mark **1001**). When a sensing element **1011** is over alignment mark **1001**, capacitance **1020** will be larger, increasing
 15 oscillation period **1026**; conversely, when a sensing element **1011** is not over alignment mark **1001**, capacitance **1020** will be smaller, decreasing oscillation period **1026**. Although it is not permitted for the undersurface of capacitive sensor **1002** to touch the upper surface of FPDS **120**, it is desirable to make the gap between capacitive sensor **1002** and FPDS **120** as small as possible to increase the variation
 20 in capacitance **1020**, thereby making the process for locating alignment mark **1001** more sensitive. The square wave **1025** on op-amp **1013** output line **1021** is the input to frequency meter **1010** which generates a time-varying frequency measurement **1029** which is a function of the distance between sensing element **1011** and alignment mark **1001**. The 25 parallel circuits combine to generate a 5 x 5 array of
 25 time-varying frequency measurements wherein the lowest frequencies (i.e., longest oscillation periods **1026**) indicate sensing elements **1011** which are directly over alignment mark **1001**, while higher frequencies correspond to sensing elements **1011** which are partially, or completely, off of alignment mark **1001**.

30 FIG. 36 shows an alignment mark **1034** underneath capacitive sensor **1002** in the case of FPDS misalignment. Table I shows the percent of overlap between various sensor elements **1011** and alignment mark **1034** in the case of misalignment between capacitive sensor **1002** and alignment mark **1034**.

0%	0%	0%	0%	0%
0%	25%	25%	0%	0%
25%	75%	75%	25%	0%
25%	75%	75%	25%	0%
0%	25%	25%	0%	0%

Table I. Sensor element **1011** signals for misalignment between capacitive sensor **1002** and alignment mark **1034**.

Comparison with Table II (for proper alignment) shows that the difference is substantial and provides a clear definition of the required displacement vector (i.e., the motion of pallet top **110** relative to FPDS **120**) which will correct the misalignment.

FIG. **37** shows alignment mark **1001** underneath capacitive sensor **1002** in the case of correct FPDS alignment. Table II shows the percent of overlap between various sensor elements **1011** and alignment mark **1001** in the case of proper alignment between capacitive sensor **1002** and alignment mark **1001**.

0%	0%	0%	0%	0%
0%	0%	100%	0%	0%
0%	100%	100%	100%	0%
0%	0%	100%	0%	0%
0%	0%	0%	0%	0%

Table II. Sensor element **1011** signals for alignment between capacitive sensor **1002** and alignment mark **1001**.

FIG. **38** shows detail view **123** (see FIG. **3**) of an alternative type of alignment mark detector using light optical illumination and imaging to find alignment mark **1001**. Note that each FPDS **120** has a number of identical alignment marks **1001**, distributed over the full area of FPDS **120** – the two alternative means for locating alignment marks shown in FIGS. **34-37** and in FIG. **38** are locating the same types of alignment marks **1001**. FIG. **3** shows both means within one pallet only for illustrative purposes – normally, a single pallet would have only one type of alignment mark detection means. Although alignment mark **1001** is underneath an insulating passivation layer, the passivation is nearly transparent so it is possible to

detect the location of alignment mark **1001** optically. Because what is important is the alignment between contactors **425** (which are part of pallet top **110**) and test pads **426** (which are part of FPDS **120** – see FIG. **17**), it is necessary to mount the optical sensor on pallet top **110** so that the alignment mechanism shown in FIGS. **39A-39B** moves contactors **425** and the optical sensor together. The optical sensor comprises imaging lens **1103**, optical transmission means **1102** (which may be a fiber optic or a prism combined with a light pipe), and an imaging sensor such as a CCD camera (not shown) – the design of optical sensors is familiar to those skilled in the art. An image of alignment mark **1101** is focused by lens **1103** through optical transmission means **1102** onto the imaging sensor, which generates an image of alignment mark **1101** – this image data is relayed to internal drive electronics **410** within pallet top **110**. Image processing functions within internal drive electronics **410** then analyze the image data to determine the location of alignment mark **1001** and the required displacement vector for pallet top **110** relative to FPDS **120** needed to correct any misalignment.

To fully characterize the misalignment between pallet top **110** and FPDS **120**, it is necessary to locate at least two alignment marks **1001** on FPDS **120**, preferably well separated to minimize errors. Given two or more required displacement vectors determined by imaging two or more alignment marks **1001** with either capacitive sensors **1002** (FIGS. **34-37**) or optical sensors (FIG. **38**), the alignment mechanism illustrated in FIGS. **39A-39B** can then be used to correct the overall X-Y-Yaw misalignment between pallet top **110** and FPDS **120**. Recalling that pallet bottom **112** is designed to prevent slippage between FPDS **120** and pallet bottom **112**, any misalignment between pallet top **110** and FPDS **120** can be considered to require an X-Y-Yaw adjustment between pallet top **110** and pallet bottom **112** as shown by vectors **1151-1154** in FIG. **39A** – an X-Y coordinate system is defined by X-axis **1171** and Y-axis **1172**. Actuators **1151-1154** are controlled by internal drive electronics **410** in pallet top **110** (see FIGS. **13-16**). Detail **1155** is shown in FIG. **39B**.

FIG. **39B** is detail view **1155** with partial cutaway **1165** of X-Y-Yaw actuators mounted between pallet top **110** and pallet bottom **112**. Two actuators **1163** and **1164** are shown, with actuator **1163** acting generally parallel to X-axis **1171** and actuator **1164** acting generally parallel to Y-axis **1172**. Actuator **1163** is attached at

point **1160** to pallet top **110**, and at point **1162** to pallet bottom **112**. Actuator **1164** is connected to pallet bottom **112** at point **1162** and to pallet top **110** at point **1161** – thus actuators **1163** and **1164**, operating in tandem with two identical actuators at the diagonally opposite corner of pallet **100** (the corner with vectors **1151** and **1152**),
5 can generate all three required alignment motions: parallel to X-axis **1171**, parallel to Y-axis **1172** and Yaw (rotation about an axis perpendicular to pallet **100**).

The placement of FPDS **120** on pallet bottom **112** by either the three-blade robot (the first embodiment) or the two-blade robot (the second embodiment) is important in determining the possible magnitude of misalignment between pallet top
10 **110** and FPDS **112**. With a sufficiently precise robot motion mechanism, the range of possible misalignments can be kept $< \sim 1\text{-}2$ mm in X and Y. The difference between the diameters of pins **204** and **206** (FIGS. **18-21**) and the diameters of holes **164** and **166** (FIG. **7**), respectively, determines the maximum range of correction for misalignments between pallet top **110** and FPDS **120**. Note that since
15 pallet **100** is disassembled into pallet top **110** and pallet bottom **112** during the process for FPDS removal and replacement, actuators **1163** and **1164** must preferably be part of pallet top **110** (since pallet top **110** has all of the internal drive electronics **410** – see FIGS. **13-16**). Thus attachment point **1162** must be able to reliably disconnect from pallet bottom **112** during pallet disassembly (between FIGS.
20 **28** and **29**). During the reverse process (going between FIGS. **29** and **28**, with arrow **214** reversed), attachment point **1162** must reconnect to pallet bottom **112**. It is not important that attachment point **1162** accurately reconnect within any tight tolerances since actuators **1163** and **1164** (as well as the corresponding actuators at the diagonally-opposite corner) can adjust for any positional nonreproducibilities). Once
25 proper alignment between pallet top **110** and FPDS **120** has been achieved, it is necessary for pallet top **110** to be locked in position with respect to pallet bottom **112** (and thus be locked relative to FPDS **120**) - this locking mechanism (see FIG. **40**) is under control of internal drive electronics **410**. The design of X-Y-Yaw actuators for use as described herein will be understood by those skilled in the art upon reading
30 the present disclosure.

FIG. **40** is a schematic detail view **124** with cutaway **1450** of a locking mechanism between pallet top **110** and pallet bottom **112** in pallet **100** in FIG. **3**. Magnetic plate **1452** is attached to pallet bottom **112**. Magnetic pole-piece **1451**,

with activating magnet coil **1453** is mounted within pallet top **110** (mounting not shown), roughly above magnetic plate **1452**. When current from internal drive circuits **410** (not shown – see FIG. **13**) flows through coil **1453**, an attractive magnetic field draws magnetic plate **1452** tightly against pole piece **1451**, thereby locking pallet top **110** to pallet bottom **112**. Magnetic plate **1452** is made somewhat larger than the opposing surfaces of pole piece **1451** to enable a certain amount of X-Y-Yaw adjustment of pallet top **110** relative to pallet bottom **112** without impairing the magnetic circuit formed by magnetic plate **1252** and pole piece **1451** – this enables the alignment procedure in FIGS. **34-39B** to operate without interfering with the locking mechanism between pallet top **110** and pallet bottom **112**. At least two locking mechanisms like that shown in view **124** would be necessary to securely lock pallet top **110** to pallet bottom **112** during pallet transfer and FPDS testing in the process chamber. It is important that the magnetic circuit design minimizes magnetic flux leakage to eliminate the possibility of interference with the electron beams used for testing. The design of locking mechanisms for use as described herein will be understood by those skilled in the art upon reading the present disclosure. The present invention also includes other methods of clamping the top and bottom together that will be apparent to those skilled in the art.

FIRST EMBODIMENT OF AN FPDS TESTING SYSTEM

The first embodiment of the present invention is an FPDS testing system comprising three main subsystems:

- 1) A pallet elevator **629**, which serves as the interface between the FPD fab and the FPDS testing system. The functions of pallet elevator **629** are the following:
 - a. Enables a robot to transport FPDSs from the FPD fab into the FPDS testing system.
 - b. Assembles pallets containing FPDSs (one per pallet) clamped between the pallet top and pallet bottom.
 - c. Performs alignment between contactors in the pallet top and test pads on the FPDS.
 - d. Assists in the transport of assembled and aligned pallets containing FPDSs ready for testing into the dual loadlock.

- e. Assists in the transport of pallets with tested FPDSs back from the dual loadlock.
 - f. Disassembles pallets with tested FPDSs.
 - g. Enables the robot to transport tested FPDSs from the FPDS testing system to the FPD fab.
- 5
- 2) A dual loadlock **575**, comprising two loadlocks, each of which has the following functions:
- a. Assists in the transport of pallets containing FPDSs for testing from the pallet elevator.
 - b. Pumps down to a vacuum level equal to that in the process chamber.
 - c. Assists in the transport of one pallet at a time into the process chamber for e-beam testing.
 - d. Assists in the removal of one pallet at a time from the process chamber after e-beam testing.
 - e. Vents to atmospheric pressure.
 - f. Assists in the transport of pallets containing tested FPDSs back to the pallet elevator.
- 10
- 15
- 20
- 3) A process chamber **522**, which has the following functions:
- a. Assists in the transport of one pallet at a time from the dual loadlock.
 - b. Tests for defective pixels on the FPDS in the pallet using one or more electron beams.
 - c. Assists in the transport of one pallet at a time back into the dual loadlock after testing.
- 25

FIG. 41 is a top view of a first embodiment of an FPDS testing system embodying the present invention, including pallet elevator **629**, dual loadlock **575**, and process chamber **522**. Pallet elevator **629** serves as the interface between the FPD fab and the multiple e-beam FPDS testing system, and is always at atmospheric pressure. Dual loadlock **575** has two separate loadlocks which cycle between atmospheric pressure and the vacuum level in process chamber **522**, typically $\sim 10^{-6}$ torr. Process chamber **522** remains at $\sim 10^{-6}$ torr at all times during

30

testing – it is vented to atmosphere only for maintenance. Valve 506 enables insertion/removal of pallets to/from upper loadlock 502 (see FIG. 43) in dual loadlock 575. Cross-section H-H is also illustrated in FIG. 41.

FIG. 42 is a schematic side view of the FPDS testing system in FIG. 41. Valves 506 and 507 enable insertion/removal of pallets to/from upper 502 and lower 505 loadlocks, respectively (see FIG. 43), in dual loadlock 575. Dual loadlock 575 sits on supports 714 which provide vertical motion capability for dual loadlock 575 to enable the two-way transfer of pallets: 1) out of process chamber 522 going into any slot in dual loadlock 575, and 2) out of any slot in dual loadlock 575 going into process chamber 522 (see FIGS. 51-58). Pallet elevator 629 sits on supports 710 which provide vertical motion capability for pallet elevator 629 to enable the two-way transfer of pallets: 1) out of any slot in dual loadlock 575 going into any slot in pallet elevator 629, and 2) out of any slot in pallet elevator 629 going into any slot in dual loadlock 575 (see FIGS. 51-58). Note that supports 710 must also move pallet elevator 629 vertically to track the motion of dual loadlock 575. Process chamber 522 sits on fixed supports 718. Supports 710, 714, and 718 preferably should provide vibration isolation to pallet elevator 629, dual loadlock 575 and process chamber 522, respectively, to ensure that there is minimal vibration of pallet 500 relative to optics assembly 520 (FIG. 43). A description of the operation of the dual loadlock 575 and process chamber 522 is provided in U. S. Patent Application Ser. No. 11/054,932 filed February 9, 2005 incorporated by reference herein. Cross-section G-G is also illustrated in FIG. 19.

FIG. 43 is a schematic view of section H-H of FIG. 41 of the FPDS testing system (pallet elevator 629 is not shown). Dual loadlock 575 is comprised of upper loadlock 502 and lower loadlock 505. A closed valve (such as valves 506 and 517) is indicated by an "X", while an open valve (such as valves 507, 516, and 518) has no "X". Two sets of bi-directional motor-driven rollers 623 and 624 define two storage slots in upper loadlock 502, and another two sets of bi-directional motor-driven rollers 625 and 626 define two storage slots in lower loadlock 505. Rollers 623-626 have three functions:

- 1) Supporting pallets within dual loadlock 575 – each set of rollers 623-626 defines a separate pallet storage slot within dual loadlock 575.

2) Assisting in transferring pallets to/from dual loadlock **575** from/to pallet elevator **629** (working in conjunction with one of the three sets of bi-directional motor-driven rollers **620-622** in pallet elevator **629** – see FIGS. **51-58**).

5 3) Assisting in transferring pallets to/from dual loadlock **575** from/to process chamber **522** (working in conjunction with bi-directional motor-driven rollers **627** in process chamber **522**).

A pallet **500** is shown being transported (arrow **530**) under optics assembly **520** by two sets of bi-directional motor-driven rollers: rollers **623** in upper loadlock **502**, and rollers **627** in process chamber **522**. Upper loadlock **502** has two slit valves: valve **506** allowing insertion/removal of pallets into/from dual loadlock **575** from/into pallet elevator **629**, and valve **516** allowing insertion/removal of pallets into/from process chamber **522**. Valve **518** (which normally remains open) enables process chamber **522** to be sealed off from dual loadlock **575** for maintenance on either dual loadlock **575** or process chamber **522**. Optics assembly **520** includes both the linear array of electron columns **1211** and the linear array of corresponding detectors **1240** (see FIG. 2). An electron beam testing procedure for FPDSs is discussed in detail in U.S. Patent Application Ser. No. 11/225,376 filed September 12, 2005 and is incorporated by reference herein.

20 During the time required to test the FPDSs in pallets **500** and **501**, the present invention provides for removal of two pallets containing already-tested FPDSs (not shown) through valve **507** from lower loadlock **505**. Two pallets **503** and **504** with FPDSs ready for testing can then be inserted into lower loadlock **505**. In FIG. **43**, valve **507** is ready to be closed (valve **517** is already closed) and lower loadlock chamber **505** will then be pumped down to the same pressure as in process chamber **522** (typically $\sim 10^{-6}$ torr).

30 After testing of the FPDSs in pallets **500** and **501**, valve **516** is closed while dual loadlock **575** indexes up to enable pallets from lower loadlock **505** to be inserted into process chamber **522** through open valves **517** and **518**. The same testing procedure described above for pallets **500** and **501** is then followed for pallets **503** and **504**. During e-beam testing, pallet **503** is supported and transported by bi-directional motor-driven rollers **625** and **627**, and pallet **504** is supported and transported by bi-directional motor-driven rollers **626** and **627**. During the time

required to test the FPDSs in pallets **503** and **504**, upper loadlock **502** is vented to atmosphere and pallets **500** and **501** are removed and replaced with two pallets containing FPDSs ready for testing (not shown), followed by a pump-down of upper loadlock **502** to the same pressure as in process chamber **522** (typically $\sim 10^{-6}$ torr).

5 This procedure of toggling between testing FPDSs from the upper and lower loadlocks enables high system throughput since there is always one loadlock (either upper loadlock **502** or lower loadlock **505**), pumped down and ready to insert pallets into process chamber **522** for testing by optics assembly **520**. All other operations, such as loadlock pumpdown and venting, pallet assembly/disassembly, pallet top-to-
10 FPDS alignment, and pallet insertion/removal into/from the dual loadlock are performed in parallel with e-beam testing and thus have no effect on system throughput.

FIG. **44** is a schematic view through section G-G of the FPDS testing system in FIG. **42**. Pallet elevator **629** is shown ready to supply pallet **628**, loaded with an
15 untested FPDS, for insertion into double loadlock **575**. FIGS. **51-58** show schematic views of the pallet insertion/removal process between pallet elevator **629** and dual loadlock **575**. Optics assembly **520** extends across the full width of pallet **500** to enable testing of all pixels on the FPDS in pallet **500** without the need for sideways (vertical in FIG. **44**) motion of pallet **500**.

20 PALLET X-Y-YAW POSITIONAL MEASUREMENT SYSTEM

FIGS. **45-47** show three schematic views through section G-G of the FPDS testing system (pallet elevator **629** and bi-directional motor-driven rollers **623-627** not shown for clarity) of FIG. **42** showing a method for measurement of the X-Y-Yaw position of pallet **572** within process chamber **522**. Optics assembly **520** is cut away
25 at both ends to show laser beams **570** and **571**. The coordinate system consists of X-axis **573** and Y-axis **574**. The position of pallet **572** along X-axis **573** is measured using sensors **550** and **551**, which can be laser interferometers, laser triangulators, or some other non-contact means of distance measurement sufficiently accurate to meet the positioning requirements dictated by the testing process performed by
30 optics assembly **520**. For e-beam FPDS testing, the positional measurement accuracy requirement is $\sim 2\text{-}10\text{ }\mu\text{m}$, substantially smaller than the dimensions of test pads **426** (see FIG. **17**). FIGS. **45-47** illustrate the use of laser positional

measurement of pallet **572**, where laser beam **568** is emitted by a laser within sensor **550** towards a reflecting surface on the side of pallet **572**. Beam **568** then reflects off the side of pallet **572** back to a detector within sensor **550**. Either through optical interference or by triangulation, sensor **550** can then determine the distance between
5 sensor **550** and the reflecting side of pallet **572**. The same positional measurement process occurs for sensor **551** emitting beam **569**, sensor **552** emitting beam **570**, and sensor **553** emitting beam **571**. Sensors **550** and **551** detect both X-axis and Yaw motion as illustrated in FIGS. **48** and **50**. Sensors **552** and **553** measure the position of pallet **572** along Y-axis **574** as shown in FIG. **49**.

10 As discussed in FIGS. **10-12**, control of internal drive electronics **410** is effected through a first data link comprising data transmitter **554**, signal beam **556**, and data receiver **442**. Feedback from internal drive electronics **410** within pallet **572** is effected by a second data link comprising data transmitter **440**, signal beam **557**, and data receiver **555**. It is necessary that pallet **572** not undergo yaw motions
15 **608** (see FIG. **50**) large enough to misalign signal beam **556** with receiver **442**, or signal beam **557** with receiver **555** – in general this requirement should not be difficult to meet, since positional errors of pallet **572** can be kept <1-2 mm through careful design of bi-directional motor-driven rollers **623-627** as is familiar to those skilled in the art. Since the overall dimensions **130** and **132** (FIG. **4**) of pallet **572** are
20 typically ~2-3 m, positional errors of ~1-2 mm will induce Yaw angles <1 mrad.

Sensors **550-553** must have the capability to track the position of pallet **572** sufficiently quickly to keep up with the pallet velocities required by the testing process performed by optics assembly **520**. From the timelines in FIGS. **64** and **70**, 40 s is typically allotted for alignment and testing – thus, with a 3 m pallet, the pallet
25 velocity during testing would be: $(3000 \text{ mm})/(40 \text{ s}) = 75 \text{ mm/s}$. Only 10 s is allotted for pallet removal in FIGS. **64** and **70**, so the pallet removal velocity would be 4x higher: $(3000 \text{ mm})/(10 \text{ s}) = 300 \text{ mm/s}$. Commercially-available laser position sensors are capable of positional measurement at these velocities as is familiar to those skilled in the art.

30 In FIG. **45**, e-beam testing has just begun, thus pallet **572** is just entering process chamber **522**. In FIG. **46**, e-beam testing is about half completed, thus pallet **572** is now half way into process chamber **522**. In FIG. **47**, e-beam testing is nearly complete, thus pallet **572** has moved almost entirely into process chamber

522. Comparison of FIGS. **45-47** shows that beams **568** and **569** strike nearly the same areas on the end of pallet **572**, regardless of the X-position of pallet **572**. Thus, only two small reflective areas (at the impact points of beams **568** and **569**) are needed on the end of pallet **572**. Beams **570** and **571** strike various positions
 5 along the entire length of pallet **572** as seen in FIGS. **45-47** – this requires that both sides of pallet **572** be reflective over their entire lengths for proper operation of sensors **552** and **553**. One benefit of having two Y-axis sensors **552** and **553** is redundancy – if either of sensors **552** or **553** fails to provide a distance measurement due to imperfections in the reflectivity of the pallet side, the other sensor will maintain
 10 measurement continuity.

FIGS. **48-50** show three schematic views through section G-G of the FPDS testing system of FIG. **42** (pallet elevator **629** and bi-directional motor-driven rollers **623-627** not shown for clarity) showing positional errors along the X-axis (FIG. **48**), Y-axis (FIG. **49**), and Yaw (FIG. **50**).

15 In FIG. **48**, pallet **600** is shown with an offset in the direction **602** from its desired position **601** along the X-axis **573** (parallel to the pallet direction of travel). X-axis positional errors are detected when sensors **550** and **551** show errors with both the same magnitude and the same sign.

20 In FIG. **49**, pallet **603** is shown with an offset in the direction **605** from its desired position **604** along the Y-axis **574** (perpendicular to the pallet direction of travel). Y-axis positional errors are detected when sensors **552** and **553** show positional errors with the same magnitude and opposite signs.

25 In FIG. **50**, pallet **606** is shown with a Yaw **608** (rotation about a vertical axis) offset from its desired orientation **607**. Yaw positional errors are detected when sensors **550** and **551** show errors with the same magnitude but with opposite signs.

30 As shown in FIG. **2**, the four position sensors **550-553** are connected to X-Y-Yaw readout **1202**, which, given the four position measurements from sensors **550-553**, calculates X-Y-Yaw positional errors, which are sent to system control **1203** over control link **1219**. System control **1203** then transmits the X-Y-Yaw positional error data to two subsystems:

- 1) Over control link **1220** to optics control **1201**, which then deflects beams **1230** to correct for positional errors. This enables the FPDS testing system to move pallet **100** at an approximately constant speed

under the linear array of columns **1211**, without the requirement for extremely accurate control of the speeds of bi-directional motor-driven rollers **627**. Further details of column **1211** are provided in FIG. **71**.

- 2) Over data line **498** to data transmitter **554**, to be sent (using beam **556**) to data receiver **442** on pallet **100** to enable internal drive electronics **410** (see FIG. **13**) to determine which voltages should be sent to various contactors **425**. This is necessary because the location of pallet **100** relative to electron columns **1211** (the X-Y-Yaw positional data) determines which pixels are located under electron beams **1230**, and thus can be tested at any particular time.

PALLET TRANSFER BETWEEN PALLET ELEVATOR, DUAL LOADLOCK AND PROCESS CHAMBER

FIGS. **51-57** are schematic views through section H-H of the FPDS testing system of FIG. **41** showing three simultaneous processes at various points in time:

- 1) Electron-beam testing by optics assembly **520** of an FPDS in pallet **600** from upper loadlock **502** which is at the same pressure ($\sim 10^{-6}$ torr) as processing chamber **522**.
- 2) Removal of pallets **602** and **603** with already-tested FPDSs from lower loadlock **505** which is at atmospheric pressure.
- 3) Insertion of pallets **604** and **605** with FPDSs ready for testing into lower loadlock **505** which is at atmospheric pressure.

FIG. **58** is the same view, shown at 120 s after FIG. **51**. Pallet elevator **629** is simplified for clarity by omission of pin plates **705-707** (see FIGS. **59-63**).

FIG. **51** is a schematic view through section H-H of the FPDS testing system of FIG. **41** showing an FPDS in pallet **600** being tested by optics assembly **520** as pallet **600** moves into process chamber **522** (arrow **610**) from upper loadlock **502** through open valves **516** and **518**. During testing, pallet **600** is supported and moved into/out of process chamber **522** by bi-directional motor-driven rollers **623** and **627**. Simultaneously, processed pallet **602** is being removed (arrow **611**) from lower loadlock **505** through open valve **507** into pallet elevator **629**. Pallet **602** is being supported and moved out of lower loadlock **505** by bi-directional motor-driven rollers **622** and **625**. Pallets **604** and **605** are ready for insertion into lower loadlock

505. Pallet elevator 629 contains three storage slots defined by bi-directional motor-driven rollers 620-622. Since upper loadlock 502 is at $\sim 10^{-6}$ torr (the same pressure as process chamber 522), valve 506 must be closed. Since lower loadlock 505 is at atmosphere for pallet transfer, valve 517 must be closed to preserve vacuum in process chamber 522 and upper loadlock 502. Two sets of bi-directional motor-driven rollers 623 and 624 define pallet storage slots in upper loadlock 502, while two more sets of bi-directional motor-driven rollers 625 and 626 define two storage slots in lower loadlock 505. The exchange of pallet 603 (containing an already-tested FPDS) will be illustrated in FIG. 55. The FPDS in pallet 601 will be tested after testing of the FPDS in pallet 600 is complete.

FIG. 52 is a schematic view through section H-H of the FPDS testing system of FIG. 41 showing an FPDS in pallet 600 being tested by optics assembly 520 as pallet 600 moves into process chamber 522 (arrow 610) from upper loadlock 502 through open valves 516 and 518. Simultaneously, pallet elevator 629 is indexing down (arrow 612) to enable the insertion of unprocessed pallet 604 from pallet elevator 629 into the upper slot (defined by bi-directional motor-driven rollers 625) of lower loadlock 505.

FIG. 53 is a schematic view through section H-H of the FPDS testing system of FIG. 41 showing an FPDS in pallet 600 being tested by optics assembly 520 as pallet 600 moves into process chamber 522 (arrow 610) from upper loadlock 502 through open valves 516 and 518. Simultaneously, unprocessed pallet 604 is being inserted (arrow 613) from pallet elevator 629 into lower loadlock 505 by bi-directional motor-driven rollers 621 and 625.

FIG. 54 is a schematic view through section H-H of the FPDS testing system of FIG. 41 showing an FPDS in pallet 600 being tested by optics assembly 520 as pallet 600 moves into process chamber 522 (arrow 610) from upper loadlock 502 through open valves 516 and 518. Simultaneously, pallet elevator 629 is indexing down (arrow 614) to enable removal of processed pallet 603 from lower loadlock 505.

FIG. 55 is a schematic view through section H-H of the FPDS testing system of FIG. 41 showing an FPDS in pallet 600 being tested by optics assembly 520 as pallet 600 moves into process chamber 522 (arrow 610) from upper loadlock 502 through open valves 516 and 518. Simultaneously, processed pallet 603 is being

removed (arrow **615**) from lower loadlock **505** into pallet elevator **629**. Pallet **603** is supported and moved out of lower loadlock **505** by bi-directional motor-driven rollers **621** and **626**.

FIG. **56** is a schematic view through section H-H of the FPDS testing system of FIG. **41** showing an FPDS in pallet **600** being tested by optics assembly **520** as pallet **600** moves into process chamber **522** (arrow **610**) from upper loadlock **502** through open valves **516** and **518**. Simultaneously, pallet elevator **629** is indexing down (arrow **616**) to enable the insertion of unprocessed pallet **605** from pallet elevator **629** into the lower slot (defined by bi-directional motor-driven rollers **626**) of lower loadlock **505**

FIG. **57** is a schematic view through section H-H of the FPDS testing system in FIG. **41** showing an FPDS in pallet **600** being tested by optics assembly **520** as pallet **600** moves into process chamber **522** (arrow **610**) from upper loadlock **502** through open valves **516** and **518**. Simultaneously, unprocessed pallet **605** is being inserted (arrow **617**) from pallet elevator **629** into lower loadlock **505** by bi-directional motor-driven rollers **620** and **626**.

FIG. **58** is a schematic view through section H-H in FIG. **41** of the FPDS testing system 120 s after FIG. **51** (see timing diagram in FIG. **64**) showing an FPDS in pallet **604** being tested by optics assembly **520** as pallet **604** moves into process chamber **522** (arrow **648**) from lower loadlock **505** through open valves **517** and **518**. During testing, pallet **604** is supported and moved into/out of process chamber **522** by bi-directional motor-driven rollers **625** and **627**. Simultaneously, processed pallet **600** is being removed (arrow **618**) from upper loadlock **502** through open valve **506** into pallet elevator **629**. Pallet **600** is being supported and moved out of upper loadlock **502** by bi-directional motor-driven rollers **622** and **623**. Since lower loadlock **505** is at $\sim 10^{-6}$ torr (the same pressure as process chamber **522**), valve **507** must be closed. Since upper loadlock **502** is at atmosphere for pallet transfer, valve **516** must be closed to preserve vacuum in process chamber **522** and lower loadlock **505**.

PALLET DISASSEMBLY AND FPDS REMOVAL FROM PALLET ELEVATOR

FIGS. **59-63** are a sequence of schematic side views of the FPDS testing system in FIG. **42**, showing various aspects of the process of disassembling pallets in pallet elevator **629**, followed by transfer of FPDSs into/out of pallet elevator **629**,

resting on supports **710**. In FIGS. **59-63**, more details of the internal mechanisms in pallet elevator **629** are shown which were omitted for clarity in FIGS. **51-58** – specifically, three pin plates **705-707**, which are mounted as shown and are supported and moved together vertically by an actuator (not shown). Dual loadlock **575** and process chamber **522** rest on supports **714** and **718**, respectively, and are not affected by any of the operations of pallet elevator **629** interacting with the FPD fab environment. The timeline in FIG. **64** shows that the pallet disassembly operations illustrated in FIGS. **59-60** (given in more detail in FIGS. **27-30**) occur in the intervals 50 - 65 s and 170 - 185 s, while the FPDS transfer operations illustrated in FIGS. **61-63** occur in the intervals 65 - 95 s and 185 - 215 s.

FIG. **59** is a schematic side view of the FPDS testing system of FIG. **42** with cutaway **799** showing two assembled pallets **701** and **702** in pallet elevator **629** (refer to FIG. **27**). Pallets **701** and **702** are supported by two sets of bi-directional motor-driven rollers **620** and **621**, respectively, which define the upper two storage slots in pallet elevator **629**. The third slot in pallet elevator **629**, defined by a third set of bi-directional motor-driven rollers **622**, is empty in this view.

FIG. **60** is a schematic side view of the FPDS testing system of FIG. **42** with cutaway **799** showing the two pallets **701** and **702** of FIG. **59** now disassembled in pallet elevator **629** (refer to FIG. **30**). Pallet top **720**, FPDS **721**, and pallet bottom **722** are now separated by pin plate **705**, which has been moved vertically upwards. Pallet top **723**, FPDS **724**, and pallet bottom **725** are now separated by pin plate **706**, which has been moved vertically upwards. Pin plate **707** has also moved vertically upwards (even though there is no pallet in the lower slot defined by bi-directional motor-driven rollers **622**) because all three pin plates **705-707** are connected to the same vertical actuator (not shown).

FIG. **61** is a schematic side view of the FPDS testing system of FIG. **42** with cutaway **799** showing a three-blade robot entering (arrow **740**) pallet elevator **629** (refer to FIG. **31**). The three-blade robot comprises three end effectors (also called "blades") **731-733** and end effector mount **730**. End effector **731** passes between FPDS **721** and pallet bottom **722**; end effector **732** passes between FPDS **724** and pallet bottom **725**; and end effector **733** enters an empty slot without a pallet. Pallet tops **720** and **723** are supported on pin plates **705** and **706**, respectively. Pin plates **705-707** may be designed with trenches which fit around bi-directional motor-driven

rollers **620-622**, respectively, to enable pin plates **705-707** to move far enough up to disassemble pallets without interference from rollers **620-622**.

FIG. **62** is a schematic side view of the FPDS testing system of FIG. **42** with cutaway **799** showing the three-blade robot lifting (arrow **741**) tested FPDSs **721** and **724** off pin plates **705** and **706**, respectively (refer to FIG. **32**).

FIG. **63** is a schematic side view of the FPDS testing system of FIG. **42** with cutaway **799** showing the three-blade robot removing (arrow **742**) tested FPDSs **721** and **724** from pallet elevator **629** into the FPD fab (refer to FIG. **33**).

The reverse process from that shown in FIGS. **59-63** is used to insert FPDSs **721** and **724** (which now should be assumed to be ready for testing, not already tested) into pallet elevator **629**:

- 1) FIG. **63**: the three-blade robot transports (arrow **742** reversed) FPDSs **721** and **724** into pallet elevator **629**.
- 2) FIG. **62**: the three-blade robot lowers (arrow **741** reversed) FPDSs **721** and **724** onto pin plates **705** and **706**, respectively.
- 3) FIG. **61**: the three-blade robot withdraws (arrow **740** reversed) from pallet elevator **629**.
- 4) FIG. **60**: pin plates **705** and **706** are now ready to assemble pallets **701** and **702** (see FIG. **59**).
- 5) FIG. **59**: pin plates **705** and **706** have been lowered by the pin plate actuator (not shown) to assemble pallets **701** and **702**, respectively.

The procedure between FIGS. **63-59** (in reverse) is shown in detail in FIGS. **33-27** (also in reverse).

The pallet disassembly/assembly and FPDS removal/insertion operations shown schematically in FIGS. **59-63** are performed in pallet elevator **629** at atmospheric pressure (preferably in a clean dry nitrogen atmosphere), in parallel with FPDS testing and loadlock venting/pumpdown as shown in the timing diagram in FIG. **64**.

TIMING DIAGRAM FOR THE FIRST EMBODIMENT OF AN FPDS TESTING SYSTEM

FIG. **64** is an operational cycle timing diagram for a first embodiment of an FPDS testing system as described in reference to FIGS. **41** and **42** – the total period

shown is 0 to 240 s, during which time four FPDSs are fully tested by optics assembly **520** in process chamber **522** (see FIG. **43**). In operation, the FPDS test system would then start back at time = 0 s (which is equivalent to 240 s), with another four pallets, going from 0 – 240 s (equivalent to 240 – 480 s) again. The three main subsystems are shown along the left side: pallet elevator **629**, dual loadlock **575** and process chamber **522**. Each horizontal line represents a particular process within the FPDS testing system – the brackets along the left side show which of the three subsystems performs the process (where more than one subsystem performs a process, the brackets overlap):

Substrates Exchange – the process of transporting FPDSs between pallet elevator **629** and the FPD fab using a three-blade robot. Details of the FPDSs exchange process, which occurs from 65 – 95 s and 185 – 215 s, are given in FIGS. **61-63**. While FPDSs are being exchanged, the pallets must be in the disassembled state.

Pallets Disassembly – the process of separating a pallet into a pallet top and a pallet bottom, to enable one FPDS to be removed and another FPDS to be inserted (Substrates Exchange line, above). Details of the pallet disassembly process, which takes place from 50 - 65 s and 170 - 185 s, are given in FIGS. **27-30**. Pallet disassembly occurs within pallet elevator **629**.

Pallets Assembly – the process of assembling a pallet from a pallet top and a pallet bottom with an FPDS is the inverse of pallet disassembly – refer to FIGS. **30-27** (reverse arrows **210**, **212**, **214**, and **216**) and takes place from 95 - 110 s and 215 - 230 s. Pallet assembly occurs within pallet elevator **629**.

Substrates Alignment – after a pallet is assembled, it is necessary to align the pallet top with the FPDS within the pallet, as described schematically in FIGS. **34-39B**. Substrates alignment, which takes place from 110 – 140 s and 230 – 260 s (equivalent to 230 – 260 s), ensures that all the contactors **425** in pallet top **110** align with test pads **426** on FPDS **120** (see FIG. **17**). Substrate alignment occurs within pallet elevator **629**.

Pallets Exchange - after the pallets with untested FPDSs in pallet elevator **629** are assembled and aligned, two other pallets containing tested FPDSs are removed from dual loadlock **575** into pallet elevator **629**. The two pallets with untested FPDSs are then inserted into dual loadlock **575** from pallet elevator **629**, as

described in FIGS. 51-57. Over the time interval from 20 – 50 s, pallet exchange is to/from lower loadlock 505, while over 140 – 170 s, pallet exchange is to/from upper loadlock 502. Pallet exchange can occur between pallet elevator 629 and dual loadlock 575 only when one of the loadlocks 502 or 505 in dual loadlock 575 has been vented to atmospheric pressure and either valve 506 (upper loadlock 505) or valve 507 (lower loadlock 505) is open (see FIGS. 51-58).

Vent Upper Loadlock – upper loadlock 502 is vented to atmospheric pressure from 120 – 140 s to enable pallet exchange between pallet elevator 629 and upper loadlock 502. Venting is preferably done with clean (i.e., particle-free) dry nitrogen and should induce minimal turbulence within upper loadlock 502 to reduce the risk of contaminating or breaking the FPDSs within upper loadlock 502.

Pump Upper Loadlock - after pallet exchange between upper loadlock 502 and pallet elevator 629 is complete, upper loadlock 502 is pumped down over the period 170 – 235 s. A number of different pumps (not shown) may be used in combination to minimize the pumpdown time as is familiar to those skilled in the art of vacuum system design:

- a. Air Ejectors – this type of pump uses pressurized gas to remove large quantities of gas from a chamber near atmospheric pressure. A typical air ejector would be the PIAB model #MLL1200 with 255 L/s pumping speed at 760 torr, dropping to 12.4 L/s at 160 torr. Below 160 torr, the air ejector(s) would be valved off from upper loadlock 502.
- b. Mechanical Pumps – this type of pump uses a piston to physically remove gas from the chamber over a pressure range from atmosphere down to 0.002 torr. A typical mechanical pump would be the Edwards model #iQDP80/iQMB1200 F with 12 L/s pumping speed at 760 torr, rising to 260 L/s at 0.1 torr, then falling back to 66 L/s at 0.002 torr. When upper loadlock 502 is below 0.002 torr, the mechanical pump(s) would be valved off from upper loadlock 502.
- c. Turbomolecular Pumps – this type of pump gives high pumping speeds for chambers at pressures of ~0.2 torr and below. A typical turbomolecular pump would be the Osaka model #TG1810 with 140 L/s pumping speed at ~0.2 torr, rising to 1800 L/s over 10^{-3} - 10^{-6} torr.

Above 0.15 torr, the turbopump(s) would be valved off from upper loadlock **502**.

A typical loadlock volume would be ~1000 L, with four air ejectors, two mechanical pumps and a turbopump needed to achieve pumpdown times of ~65 s from atmosphere to $\sim 10^{-6}$ torr.

Note that the lower loadlock **505** pumpdown occurs from 50 - 115 s (see below), so there is no overlap in time between the lower loadlock **505** pumpdown and the upper loadlock **502** pumpdown – this means that the same set of pumps can be used for pumping down both the upper **502** and lower **505** loadlocks. If it is possible to maintain $\sim 10^{-6}$ torr in upper loadlock **502** and lower loadlock **505** using only the process chamber **522** pumping system (not shown), then no dedicated pumps for either the upper **502** or lower **505** loadlocks will be necessary. Otherwise, two small sustaining turbopumps (one for each of the upper **502** and lower **505** loadlocks) could be used to maintain $\sim 10^{-6}$ torr after the main set of pumpdown pumps (described above) is diverted over to the other loadlock.

Upper Loadlock at Air or Vacuum – after pumping upper loadlock **502** down to $\sim 10^{-6}$ torr, one or more turbopumps (not shown) may remain connected to upper loadlock **502**, maintaining upper loadlock **502** at $\sim 10^{-6}$ torr (the same vacuum level as in process chamber **522**) over the period 235 – 120 s. Note that 120 s is equivalent to 360 s (= 120 s + 240 s cycle time), since the FPD testing system cycles through the full timeline in FIG. **64** repeatedly, testing four FPDs every 240 s. It may be possible to maintain $\sim 10^{-6}$ torr in upper loadlock **502** using only the process chamber **522** pumping system (not shown).

Vent Lower Loadlock – lower loadlock **505** is vented to atmospheric pressure from 0 – 20 s to enable pallet exchange between pallet elevator **629** and lower loadlock **505**. Venting is preferably done with clean (i.e., particle-free) dry nitrogen and should induce minimal turbulence within lower loadlock **505** to minimize the risk of contaminating or breaking the FPDs within lower loadlock **505**.

Pump Lower Loadlock - after pallet exchange between lower loadlock **505** and pallet elevator **629** is complete, lower loadlock **505** is pumped down over the period 50 – 115 s. The same pumping considerations apply to lower loadlock **505** as apply to upper loadlock **502**.

Lower Loadlock at Air or Vacuum – after pumping lower loadlock **505** down to $\sim 10^{-6}$ torr, one or more turbopumps (not shown) may remain connected to lower loadlock **505**, maintaining lower loadlock **505** at $\sim 10^{-6}$ torr (the same vacuum level as in process chamber **522**) over the period 115 – 240 s. It may be possible to maintain
 5 $\sim 10^{-6}$ torr in lower loadlock **505** using only the process chamber **522** pumping system (not shown).

Index Dual Loadlock – the dual loadlock **575** has four slots for supporting pallets. These slots are defined by the four sets of bi-directional motor-driven rollers **623-626**. (see FIG. **43**). For insertion/removal of pallets into/from process chamber
 10 **522**, is necessary to move dual loadlock **575** vertically to align each of the four slots with rollers **527** in process chamber **522** – this vertical motion and alignment is called “indexing”. Precise indexing (to precisions < 1 mm) is preferable for the pallet to align properly with optics assembly **520** since during almost the full period of e-beam testing, a pallet is supported both by rollers in dual loadlock **575** (i.e., one of the four
 15 sets of rollers **623-626**) as well as by rollers **627** in process chamber **522** (see FIG. **43** – note that pallet **500** is being tested by optics assembly **520** while still being partially supported by bi-directional motor-driven rollers **623** in upper loadlock **502**). During indexing, which occurs four times during the 240 s cycle (55 – 60 s, 115 – 120 s, 175 – 180 s, and 235 – 240 s), dual loadlock **575** moves with respect to
 20 process chamber **522**, necessitating a movable vacuum seal between dual loadlock **575** and process chamber **522**, as discussed in U. S. Patent Application Ser. No. 11/054,932 filed February 9, 2005 incorporated by reference herein.

Insert or Remove Pallet – this line in the timing diagram covers both the insertion of pallets from dual loadlock **575** into process chamber **522** (times 0 – 5 s, 60 – 65 s, 120 – 125 s, and 180 – 185 s – marked “I”), as well as the removal of
 25 pallets from process chamber **522** into dual loadlock **575** (times 45 – 55 s, 105 – 115 s, 165 – 175 s, and 225 – 235 s – marked “R”). The removal times are longer than the insertion times because alignment and testing of an FPDS begins after the pallet has traveled only a short distance into process chamber **522** (see FIG. **43**),
 30 while pallet removal involves travelling back (reverse arrow **530** in FIG. **43**) the full length of process chamber **522**.

Align and Test Substrate – this line represents the times required for alignment and testing of FPDSs (in pallets) using optics assembly **520** in process

chamber **522**. "Alignment" refers to the process of locating alignment marks (not shown – these are different marks from alignment marks **1001** in FIGS. **34-38**) using each of the multiple e-beams from optics assembly **520**. When the alignment marks have been located with the e-beams from optics assembly **520**, it is then possible to
5 locate the various pixel electrodes (not shown) on FPDS **120** to perform e-beam testing of individual pixels for defects as discussed in U. S. Patent Application Ser. No. 11/225,376 filed September 12, 2005 and in U. S. Patent Application Ser. No. 11/093,000 filed March 28, 2005, both incorporated by reference herein. The "align and test substrates" operation occurs four times during the 240 s cycle: 5 – 45 s, 65
10 – 105 s, 125 – 165 s, and 185 – 225 s.

SECOND EMBODIMENT OF AN FPDS TESTING SYSTEM

The first embodiment of the present invention discussed above requires a separate pallet elevator **629** to feed pallets into dual loadlock **575**. After loading into pallet elevator **629**, pallets are transported to either the upper **502** or lower **505**
15 loadlocks in dual loadlock **575**, pumped down, and then inserted into process chamber **522** for e-beam testing. One disadvantage of this arrangement is the need for FPD fab floor space to accommodate pallet elevator **629**. Another disadvantage is the extra cost required for a separate pallet elevator **629**, in addition to the dual loadlock **575** and process chamber **522**.

20 A second embodiment of the present invention will now be described in reference to FIGS. **65-70** that eliminates these disadvantages by integrating the pallet assembly/disassembly functions of the pallet elevator into the dual loadlock. A summary of this embodiment includes:

- 1) Dual loadlock **899**, which serves as the interface between the FPD fab
25 and the FPDS testing system. The functions of dual loadlock **899** are the following:
 - a. Enables a robot to transport FPDSs from the FPD fab into the FPDS testing system.
 - b. Assembles pallets containing the FPDSs for testing.
 - 30 c. Performs alignment between the contactors in the pallets and the test pads on the FPDSs.

d. Pumps down to a vacuum level equal to that in process chamber **804**.

e. Assists in the transport of the pallets (one at a time) into process chamber **804** for e-beam testing.

5 f. Assists in the removal of the pallet (one at a time) from process chamber **804** after e-beam testing.

g. Vents to atmospheric pressure.

h. Disassembles the pallets with the tested FPDSs.

10 i. Enables the robot to transport the tested FPDSs out of the FPDS testing system to the FPD fab.

2) A process chamber **804** which has the following functions:

a. Assists in the transport of one pallet at a time from the dual loadlock.

15 b. Tests for defective pixels on the FPDS in the pallet using one or more electron beams.

c. Assists in the transport of one pallet at a time back into the dual loadlock after testing.

20 One disadvantage of the second embodiment relative to the first embodiment is the increased complexity of mechanisms within dual loadlock **899**. Another disadvantage is the need for higher pumping capacity to enable pumpdown times consistent with the timeline in FIG. **70** due to the larger volume of dual loadlock **899** compared with dual loadlock **575**.

25 FIG. **65** is a schematic top view of a second embodiment of an FPDS testing system embodying the present invention, including dual loadlock **899** and process chamber **804**. Dual loadlock **899** comprises two loadlocks **800** and **801** (see FIGS. **67-69**) which cycle between atmospheric pressure and the vacuum level in the process chamber **804**, typically $\sim 10^{-6}$ torr. Interface plate **805** is part of the sliding vacuum seal between dual loadlock **899** and process chamber **804**. Aspects of moving vacuum seals are discussed in U. S. Patent Application Ser. No. 11/054,932
30 filed February 9, 2005 incorporated by reference herein. Process chamber **804** remains at $\sim 10^{-6}$ torr except during maintenance. Cross-section K-K is also illustrated in FIG. **65**.

FIG. 66 is a schematic side view of the FPDS testing system in FIG. 65. Valves 802 and 803 enable insertion/removal of pallets into/from dual loadlock 899. Dual loadlock 899 sits on supports 810 which provide vertical motion capability for dual loadlock 899 to enable the two-way transfer of pallets: 1) out of process chamber 804 going into any slot in dual loadlock 899, and 2) out of any slot in dual loadlock 899 going into process chamber 804 (see FIG. 67 for the definitions of loadlock slots). Process chamber 804 sits on fixed supports 814. All of supports 810 and 814 should provide vibration isolation to dual loadlock 899 and process chamber 804, respectively, to ensure that there is no vibration of pallets 807 and 907 relative to optics assembly 806 (see FIGS. 67 and 69). A two-blade robot comprising end effectors 831-832 and end effector mount 830 can be seen entering dual loadlock 899 from the left. Interface plate 805 extends high enough to accommodate the range of motion of dual loadlock 899 relative to process chamber 804 required for indexing all four slots in dual loadlock 899 with process chamber 804 (compare FIG. 67 with FIG. 69).

FIG. 67 is a schematic view through section K-K of the FPDS testing system in FIG. 65. Dual loadlock 899 includes upper loadlock 800 and lower loadlock 801. In FIG. 67, a closed valve (such as valves 802 and 861) is indicated by an "X", while an open valve (such as valves 803, 860, and 862) has no "X". Two sets of bi-directional motor-driven rollers 820 and 821 define two pallet storage slots in upper loadlock 800, and another two sets of bi-directional motor-driven rollers 852 and 855 define two pallet storage slots in lower loadlock 801. Rollers 820, 821, 852, and 855 have two functions:

- 1) Supporting pallets within dual loadlock 899 – each set of rollers 820, 821, 852, and 855 defines a separate pallet storage slot within dual loadlock 899.
- 2) Assisting in transferring pallets between dual loadlock 899 and process chamber 804 (working in conjunction with bi-directional motor-driven rollers 856 in process chamber 804).

Bi-directional motor-driven rollers 856 support and transport pallets within process chamber 804. Pallet 807 is shown being transported (arrow 823) under optics assembly 806 by two sets of bi-directional motor-driven rollers: rollers 820 in upper loadlock 800, and rollers 856 in process chamber 804. Upper loadlock

chamber **800** has two valves: valve **802** allowing insertion/removal of pallets into/from dual loadlock **899** from/to the FPD fab, and valve **860** allowing insertion/removal of pallets into/from process chamber **804**. For pallet transfer to/from process chamber **804**, upper loadlock **800** must be at the same pressure as process chamber **804** ($\sim 10^{-6}$ torr) – this requires valve **802** to be closed, and valves **860** and **862** to be open. Valve **862** (which normally remains open) enables process chamber **804** to be sealed off from dual loadlock **899** for maintenance on either dual loadlock **899** or process chamber **804**. Lower loadlock **801** is shown with valve **803** open to enable the removal/insertion of FPDSs. Since FPDS removal requires lower loadlock **801** to be at atmospheric pressure, valve **861** must be closed to preserve the $\sim 10^{-6}$ torr pressure in upper loadlock **800** and process chamber **804**. Optics assembly **806** comprises the linear array of electron columns **1211** and the linear array of corresponding detectors **1240** (see FIG. 2). An electron beam testing procedure for FPDSs is discussed in detail in U.S. Patent Application Ser. No. 11/225,376 filed September 12, 2005 incorporated by reference herein.

During the time required to test the FPDSs in pallets **807** and **808** (see timeline in FIG. **70**), two pallets with already-tested FPDSs are disassembled (see FIGS. **27-30**) within lower loadlock **801** so that the already-tested FPDSs (not shown) can be removed by a two-blade robot through valve **803**. Two FPDSs **840** and **841** ready for testing are then inserted into lower loadlock **801** by the two-blade robot consisting of end effectors (or “blades”) **831** and **832** and end effector mount **830** – the two-blade robot is shown leaving (arrow **824**) lower loadlock **801** after loading the two FPDSs **840** and **841** onto pin plates **857** and **858**, respectively (see FIGS. **33-31** with arrows **250**, **246**, and **244** reversed). Valve **803** would then be closed and lower loadlock **801** pumped down to the same pressure as in process chamber **804** (typically $\sim 10^{-6}$ torr). While lower loadlock **801** is pumping down, the two pallets in lower loadlock **801** are reassembled by pin plates **857** and **858** (see FIGS. **30-27** with arrows **214**, **212**, and **210** reversed). The next step is alignment of pallet tops **850** and **853** to FPDSs **840** and **841**, respectively, (see timeline in FIG. **70**). After assembly, the pallet in the upper slot (defined by rollers **852**) in lower loadlock **801** will consist of pallet top **850** and pallet bottom **851** with FPDS **840** contained therein; the pallet in the lower slot (defined by rollers **855**) in

lower loadlock **801** will consist of pallet top **853** and pallet bottom **854** with FPDS **841** contained therein.

A vertical actuator (not shown) moves pin plates **822** and **823** vertically to enable the pallet disassembly [assembly] procedure illustrated in FIGS. **27-30** [**30-27**] to be performed simultaneously on both pallets within upper loadlock **800**. In FIG. **67**, pin plates **822** and **823** are shown in the lower position, leaving pallets **807** and **808** assembled (see FIG. **27**) and allowing pallets **807** and **808** to be transported by rollers **820** and **821**, respectively. Pin plates **857** and **858** are in their upper position, disassembling the two pallets in lower loadlock **801** (see FIG. **30**).

FIG. **68** is a schematic view through section L-L of the FPDS testing system in FIG. **66** at the same point on the timeline (FIG. **70**) as in FIG. **67**. Because pallet **807** has moved (arrow **823**) mostly into process chamber **804**, pin plate **822** in upper loadlock **800** can be clearly seen. In particular, the trenches **865** in pin plate **822** which allow clearance for bi-directional motor-driven rollers **820** are visible, along with both long pins **204** and short pins **206**. The two-blade robot (comprised of end effectors **831**, **832**, and end effector mount **830**), is leaving (arrow **824**) lower loadlock **801** at the left.

FIG. **69** is a schematic view through section K-K of the FPDS testing system in FIG. **65** showing an FPDS in pallet **907** from lower loadlock **801** being tested while the two-blade robot is entering upper loadlock **800**. The view in FIG. **69** is 120 s after FIG. **67** – all the functions occurring in upper loadlock **800** in FIG. **67** are now occurring in lower loadlock **801**, and all the functions occurring in lower loadlock **801** in FIG. **67** are now occurring in upper loadlock **800**. 120 s after FIG. **69**, the FPD testing system would again be in the status shown in FIG. **67** (see the timeline in FIG. **70**).

After testing of the FPDSs in pallets **807** and **808** as described in reference to FIG. **67**, valve **860** was closed and dual loadlock **899** indexed up to enable pallet **907** from lower loadlock **801** to be inserted into process chamber **804** through open valves **861** and **862**. The same testing procedure described in FIG. **67** for pallets **807** and **808** is then followed for pallets **907** and **908** from lower loadlock **801**. During e-beam testing, pallet **907** in the upper slot of lower loadlock **802** is supported and transported (arrow **890**) by bi-directional motor-driven rollers **852** and **856**, and pallet **908** in the lower slot of lower loadlock **801** is supported and transported by bi-

directional motor-driven rollers **855** and **856**. During the time required to test the FPDSs in pallets **907** and **908** from lower loadlock **801**, upper loadlock **800** is vented to atmosphere, pallets **807** and **808** (see FIG. 67) are disassembled, and the two already-tested FPDSs removed by the two-blade robot. Pallet item numbers **807** and **808** are indicated in brackets and the operation of removal indicated by arrow **891**. Next, two FPDSs **940** and **941** ready for testing are inserted, followed by pallet reassembly and alignment of pallet tops **950** and **953** to FPDSs **940** and **941**, respectively. Insertion of FPDSs **940** and **941** would be indicated by a reverse direction of arrow **891**. After assembly, the pallet in the upper slot (defined by rollers **820**) of upper loadlock **800** will consist of pallet top **950** and pallet bottom **951** with FPDS **940** therein; the pallet in the lower slot (defined by rollers **821**) of upper loadlock **800** will consist of pallet top **953** and pallet bottom **954** with FPDS **941** therein. The two-blade robot (comprised of end effectors **831**, **832**, and end effector mount **830**), is leaving (arrow **891**) upper loadlock **800** at the left through open valve **802**.

For pallet transfer to/from process chamber **804**, lower loadlock **801** must be at the same pressure as process chamber **804** ($\sim 10^{-6}$ torr) – this requires valve **803** to be closed, and valves **861** and **862** to be open to allow pallet transfer. Upper loadlock **800** is shown with valve **802** open to enable the removal/insertion of FPDSs. Since FPDS removal requires upper loadlock **800** to be at atmospheric pressure, valve **860** must be closed to preserve the $\sim 10^{-6}$ torr pressure in lower loadlock **801** and process chamber **804**.

This procedure of toggling between testing FPDSs from the upper **800** and lower **801** loadlocks enables high system throughput since there is always one loadlock (either upper loadlock **800** or lower loadlock **801**), pumped down and ready to insert pallets into process chamber **804** for testing by optics assembly **806**. All other operations, such as loadlock pumpdown and venting, pallet assembly/disassembly, pallet top-to-FPDS alignment, and FPDS insertion/removal are performed in parallel with e-beam testing and thus have no effect on system throughput.

Process chamber **804** in the second embodiment of the present invention functions identically to process chamber **522** in the first embodiment, including all aspects of e-beam testing, X-Y-Yaw position measurement (FIGS. 2 and 45-50), and

communications to/from the pallet (FIGS. 2 and 10-12). The pallet design (FIGS. 13-16) and pallet disassembly and assembly procedures (FIGS. 27-30 and 30-27, respectively) are also identical for the two embodiments.

TIMING DIAGRAM FOR THE SECOND EMBODIMENT OF AN FPDS TESTING 5 SYSTEM

FIG. 70 is an operational cycle timing diagram for the second embodiment of an FPDS testing system in FIGS. 65 and 66 – the total period shown is 0 to 240 s, during which time four FPDSs are fully tested by optics assembly 806 in process chamber 804 (see FIG. 67). In operation, the FPD testing system would then start
10 back at time = 0 s (which is equivalent to 240 s), with another four pallets, going from 0 – 240 s (equivalent to 240 – 480 s) again. The differences and similarities of the second embodiment shown in FIGS. 65 and 66 (with a timing diagram in FIG. 70) relative to the first embodiment in FIGS. 41 and 42 (with a timing diagram in FIG. 64) are:

- 15 1) No pallet elevator – the functions of pallet elevator 629 in the first embodiment are now performed within dual loadlock 899 in the second embodiment.
- 2) Dual loadlock 899 contains pin plates 822-823 (in upper loadlock 800) and pin plates 857-858 (in lower loadlock 801). In the second
20 embodiment, instead of transferring pallets out to a pallet elevator, FPDSs are directly inserted and removed from dual loadlock 899. The pin plate actuators for the second embodiment must operate within a vacuum environment in dual loadlock 899, unlike the atmospheric pressure environment in pallet elevator 629 – this may add some
25 complexity to the system as well as the need for in-vacuum mechanical motions (i.e., pins 204 and 206 must slide through holes 164 and 166, respectively, under vacuum).
- 3) The upper 800 and lower 801 loadlocks are now larger to
30 accommodate pin plates 822-823 and 857-858, respectively – this will require increased pumping capacity to achieve the necessary loadlock pumpdown times to maintain the desired system throughput (compare timelines in FIGS. 64 and 70). This also requires valves 802-803 and

860-861 in the second embodiment to be larger (wider in the vertical direction) than the corresponding valves **506-507** and **516-517**, respectively, in the first embodiment (compare FIGS. **43** and **67**).

- 4) Reduced system footprint – the FPDS testing system footprint is substantially reduced in the second embodiment by eliminating pallet elevator **629** – this is a significant advantage since FPD fab floor space is typically at a premium.
- 5) Process chamber **804** – essentially unchanged from process chamber **522** in the first embodiment – the only significant exception being supports **814**, which must be taller than supports **718** to accommodate the increased travel of dual loadlock **899** during indexing relative to the travel of dual loadlock **575** (compare FIGS. **42** and **66**).

The two main subsystems are shown along the left side of FIG. **70**: dual loadlock **899** and process chamber **804**. Each horizontal line represents a particular process within the FPDS testing system – the brackets along the left side show which of the two subsystems performs the process (where more than one subsystem performs a process, the brackets overlap):

Substrates Exchange – the process of transporting FPDSs between dual loadlock **899** and the FPD fab using a two-blade robot. The substrate exchange process occurs from 20 – 50 s (into/out of lower loadlock **801** – see FIGS. **67-68**) and 140 – 170 s (into/out of upper loadlock **800** – see FIG. **69**) in the 240 s cycle. While FPDSs are being exchanged, the pallets must be in the disassembled state and the respective loadlock must be at atmospheric pressure.

Pallets Disassembly – the process of separating a pallet into a pallet top and a pallet bottom for holding a FPDS, to enable the FPDS to be removed and another FPDS to be inserted (Substrates Exchange line, above). Details of the pallet disassembly process, which takes place from 5 - 20 s (in lower loadlock **801**) and 125 - 140 s (in upper loadlock **800**), are given in FIGS. **27-30**. Simultaneously with pallet disassembly, the loadlock chamber containing the pallets being disassembled continues venting: either lower loadlock **800** (during 0 - 20 s) or upper loadlock **801** (during 120 - 140 s).

Pallets Assembly – the process of assembling a pallet from a pallet top and a pallet bottom with a FPDS is the inverse of pallet disassembly – refer to FIGS. **30-27**

(reverse arrows **210**, **212**, **214**, and **216**). Pallet assembly takes place from 50 – 65 s (in lower loadlock **801**) and 170 – 185 s (in upper loadlock **800**). Simultaneously with pallet assembly, the loadlock chamber containing the pallets under assembly starts pumping down: either lower loadlock **800** (during 50 – 115 s) or upper loadlock **801** (during 170 – 235 s).

Substrates Alignment – after a pallet is assembled, it is necessary to align the pallet top with the FPDS within the pallet, as described schematically in FIGS. **34-39B**. Substrates alignment, which takes place from 65 – 100 s (in lower loadlock **801**) and 185 – 220 s (in upper loadlock **800**), ensures that all the contactors **425** in pallet top **110** align with the test pads **426** on FPDS **120** (see FIG. **17**). Simultaneously with substrates alignment, the loadlock chamber containing the pallets being aligned continues pumping down: either lower loadlock **800** (during 50 – 115 s) or upper loadlock **801** (during 170 – 235 s).

Vent Upper Loadlock – upper loadlock **800** is vented to atmospheric pressure from 120 – 140 s to enable FPDS exchange between upper loadlock **800** and the FPD fab (outside the system – not shown). Venting is preferably done with clean (i.e., particle-free) dry nitrogen and should induce minimal turbulence within upper loadlock **800** to reduce the risk of contaminating or breaking the FPDSs within upper loadlock **800**.

Pump Upper Loadlock - after FPDS exchange between upper loadlock **800** and the FPD fab is complete, upper loadlock **800** is pumped down over the period 170 – 235 s. The same combination of different pumps (not shown - see FIG. **64**) as were described in the first embodiment may be used to minimize the pumpdown time as is familiar to those skilled in the art of vacuum system design. A typical loadlock volume would be ~2000 L, with multiple air ejectors, mechanical pumps and turbopumps needed to achieve pumpdown times of ~65 s from atmosphere to ~ 10^{-6} torr – due to the larger volume of upper loadlock **800** relative to upper loadlock **502**, a larger number of pumps may be required to achieve the necessary ~65 s pumpdown time.

Note that the lower loadlock **801** pumpdown occurs from 50 - 115 s (see below), so there is no overlap in time between the lower loadlock **801** pumpdown and the upper loadlock **800** pumpdown – this means that the same set of pumps can be used for pumping down both the upper and lower loadlocks. With apparatus

sufficient to maintain $\sim 10^{-6}$ torr in upper loadlock **800** and lower loadlock **801** using only the process chamber **804** pumping system (not shown), then no dedicated pumps for either the upper **800** or lower **801** loadlocks will be necessary. Otherwise, two small sustaining turbopumps (one for each of the upper **800** and lower **801** loadlocks) could be used to sustain $\sim 10^{-6}$ torr after the main set of pumpdown pumps (described above) is diverted over to the other loadlock.

Upper Loadlock at Air or Vacuum – after pumping upper loadlock **800** down to $\sim 10^{-6}$ torr, one or more turbopumps (not shown) may remain connected to upper loadlock **800**, maintaining upper loadlock **800** at $\sim 10^{-6}$ torr (the same vacuum level as in process chamber **804**) over the period 235 – 120 s. Note that 120 s is equivalent to 360 s (= 120 s + 240 s cycle time), since the FPD testing system cycles through the full 240 s timeline in FIG. 70 repeatedly, testing four FPDSs every 240 s. Alternatively, $\sim 10^{-6}$ torr in upper loadlock **800** can be maintained with a compatible process chamber **804** pumping system (not shown).

Vent Lower Loadlock – lower loadlock **801** is vented to atmospheric pressure from 0 – 20 s to enable FPDS exchange between lower loadlock **801** and the FPD fab (outside the tool – not shown). Venting is preferably done with clean (i.e., particle-free) dry nitrogen and should induce minimal turbulence within lower loadlock **801** to reduce the risk of contaminating or breaking the FPDSs within lower loadlock **801**.

Pump Lower Loadlock - after FPDS exchange between lower loadlock **801** and the FPD fab is complete, lower loadlock **801** is pumped down over the period 50 – 115 s. The same pumping considerations apply to lower loadlock **801** as applied to upper loadlock **800**.

Lower Loadlock at Air or Vacuum – after pumping lower loadlock **801** down to $\sim 10^{-6}$ torr, one or more turbopumps (not shown) may remain connected to lower loadlock **801**, maintaining lower loadlock **801** at $\sim 10^{-6}$ torr (the same vacuum level as in process chamber **804**) over the period 115 – 240 s. Alternatively, $\sim 10^{-6}$ torr in lower loadlock **801** can be maintained with a compatible process chamber **804** pumping system (not shown).

Index Dual Loadlock – the dual loadlock **899** has four slots for supporting pallets. These slots are defined by the four sets of bi-directional motor-driven rollers **820**, **821**, **852**, and **855**. (see FIG. 67). For insertion/removal of pallets into/from

process chamber **804**, it is necessary to move dual loadlock **899** vertically to align each of the four slots with rollers **856** in process chamber **804** – this vertical motion and alignment is called “indexing”. Precise indexing (to precisions <1 mm) is preferable for the pallet to align properly with optics assembly **806** since during

5 almost the full period of e-beam testing, a pallet is supported by both the rollers in dual loadlock **899** (i.e., one of the four sets of rollers **820**, **821**, **852**, or **855**) and rollers **856** in process chamber **804** (see FIG. **67** – note that pallet **807** is being tested by optics assembly **806** while still being partially supported by bi-directional motor-driven rollers **820** in upper loadlock **800**). During indexing, which occurs four

10 times during the 240 s cycle (55 – 60 s, 115 – 120 s, 175 – 180 s, and 235 – 240 s), dual loadlock **899** moves with respect to process chamber **804**, necessitating a movable vacuum seal between dual loadlock **899** and process chamber **804**, as discussed in U. S. Patent Application Ser. No. 11/054,932 filed February 9, 2005 incorporated by reference herein. Sealing plate **805** works in conjunction with the

15 opposing surface on dual loadlock **899** as part of the sliding seal, which optionally may have a bellows seal.

Insert or Remove Pallet – this line in the timing diagram covers both the insertion of pallets from dual loadlock **899** into process chamber **804** (times 0 – 5 s, 60 – 65 s, 120 – 125 s, and 180 – 185 s – marked “I”), as well as the removal of

20 pallets from process chamber **804** into dual loadlock **899** (times 45 – 55 s, 105 – 115 s, 165 – 175 s, and 225 – 235 s – marked “R”). The removal times are longer than the insertion times because alignment and testing of an FPDS begins after the pallet has traveled only a short distance into process chamber **804** (see FIG. **67**), while pallet removal involves travelling back (reverse arrow **823** in FIG. **67**) the full

25 length of process chamber **804**.

Align and Test Substrate – this line represents the times required for alignment and testing of FPDSs (in pallets) using optics assembly **806** in process chamber **804**. “Alignment” refers to the process of locating alignment marks (not shown – these are different marks from alignment marks **1001** in FIGS. **34-38**) using

30 each of the multiple e-beams from optics assembly **806**. When the alignment marks have been located with the e-beams from optics assembly **806**, it is then possible to locate the various pixel electrodes (not shown) on FPDS **120** to perform e-beam testing of individual pixels for defects as discussed in U. S. Patent Application Ser.

No. 11/225,376 filed September 12, 2005 and in U. S. patent Application Ser. No. 11/093,000 filed March 28, 2005, both incorporated by reference herein. The align and test substrates operation occurs four times during the 240 s cycle: 5 – 45 s, 65 – 105 s, 125 – 165 s, and 185 – 225 s.

5 SCHEMATIC VIEW OF THE ELECTRON OPTICAL COLUMN AND DETECTOR OPTICS

FIG. 71 is a schematic cross-section of an electron optical column **1211** and the corresponding detector **1240** shown in FIG. 2 in a plane containing the optical axis of one column and parallel to the main scan axis. Electrons **1503** are emitted by source tip **1501** under the influence of a high electric field generated by a voltage difference between source tip **1501** and extraction electrode **1504**, typically 2700-3400 V. Suppressor electrode **1502** is typically biased negative relative to source tip **1501** to suppress electron emission from the shank (upper cylindrical portion) of source tip **1501**, since this emission cannot be used to form the electron beam. The source lens includes extraction electrode **1504**, source lens electrode **1505**, and beam-limiting aperture (BLA) **1520**. Electrons passing through BLA **1520** enter the double-deflection beam blanker comprised of electrodes **1507** and **1508**. In FIG. 71, the blanker is inactivated, so beam **1506** is not deflected off the optical axis, and passes through the blanking and pumping aperture (BPA) **1510** and into the main lens. The purpose of the double-deflection blanker is to turn the beam on and off at the surface of FPDS **120**.

The main lens includes electrodes **1511**, **1512**, and **1513**, forming a focused spot **1521** on the surface of FPDS **120**. The stigmator/deflector **1515** deflects the beam **1230** and corrects beam shape distortions caused by the beam deflection. Detector **1240** collects signal electrons **1244** emitted from the upper surface of the FPDS **120** at location **1521** due to the interaction of the primary beam **1230** with the material in the substrate **120**. A 4000 V bias relative to the substrate surface **120** may be applied to detector **1240**, causing signal electrons **1244** to be attracted to detector **1240**. The detector optics designs in U.S. Patent No. 6,777,675 B2 and U.S. Appl. No. 10/833,949, incorporated by reference herein, illustrate a similar detector optics design (this design is for a generally cylindrically symmetric detector optics). Electrical connections **1212** to column **1211** include cables **1540-1550**,

connecting to optical elements **1501**, **1502**, **1504**, **1505**, **1507**, **1508**, **1510**, **1511**, **1512**, **1513**, and **1515**, respectively.

The X-Y-Yaw data received by system control **1203** from X-Y-Yaw readout **1202** is relayed to optics control **1201** through control link **1220** (see FIG. 2). Optics control **1201** uses the X-Y-Yaw data to control the deflection signals sent to each of the stigmator/deflectors **1515** through cables **1212** connecting to columns **1211**. By inducing X-Y deflections to beams **1230**, the optics control **1201** can place each beam **1230** in the proper location on the surface of FPDS **120**, counteracting any X, Y, or Yaw errors due to imperfections in the motion of pallet **100** within the process chamber (not shown).

It will be understood by those skilled in the art that the foregoing descriptions are for illustrative purposes only. A number of modifications are possible within the scope of the present invention, such as:

- 1) The pallet elevator in the first embodiment may serve only as a storage location for assembled pallets, prior to insertion into the dual loadlock, with the pallet disassembly/assembly operations conducted outside the FPDS testing system. The robot would then transfer assembled pallets into/out of the pallet elevator, instead of FPDSs. In this example, there would be no need for pin plates within the pallet elevator, thereby simplifying the system.
- 2) The dual loadlock in the second embodiment may serve only as a storage location for assembled pallets, prior to insertion into the process chamber, with the pallet disassembly/assembly operations conducted outside the FPDS testing system. The robot would then transfer assembled pallets into/out of the dual loadlock, instead of FPDSs. In this example, there would be no need for pin plates within the dual loadlock, thereby simplifying the system.
- 3) Instead of applying the present invention to the testing of FPDSs, other large substrate applications are also possible using the present invention:
 - a. A system for electron beam direct-write (EBDW) lithography using the present invention is possible. In this example, a simplified pallet design could be used, not requiring internal

drive electronics. The use of a pallet, in conjunction with a linear array of electron beam columns spanning the full width of the substrate, would eliminate the need for costly and complex X-Y stages for moving the FPDS under the electron beam for patterning the thin film transistors and pixel areas.

b. Other processes used for the fabrication of FPDSs are also possible, such as CVD, PVD, etc. In these cases, the pallet would also be simpler than for e-beam testing of FPDSs, since no electrical contacts to the test pads are necessary. Advantages could include control of the FPDS temperature distribution through the use of heaters within the pallet. Instead of an array of electron beam columns, a linear processing head would be substituted – the processing head could be a linear PVD source, or a linear array of CVD gas jets.

4) The present invention can be applied to electron beam FPD testing and/or direct-write lithography systems with arrangements of the electron columns differing from the linear arrangement shown in FIG. 2. These alternative arrangements include multiple linear arrays of columns, columns in arrangements other than an X-Y grid, or multiple arrays of columns wherein some columns are specifically designed for e-beam direct-writing of small features (such as TFT source, gate and drain lines) while other columns are specifically designed for writing of larger features such as pixel electrodes.

5) The present invention may also be applied to ion beams, instead of electron beams, for various processes to be applied to large substrates, such as:

- a. Microanalysis of large substrates for process feedback during fabrication.
- b. Ion beam milling or micromachining of large substrates.
- c. Ion beam direct-write (IBDW) lithography of large substrates, including, but not limited to FPDSs.

Although the present invention has been described above in terms of specific embodiments, it is anticipated that alterations and modifications thereof will no doubt

become apparent to those skilled in the art. It is therefore intended that the following claims be interpreted as covering all such alterations and modifications as fall within the true spirit and scope of the invention.